

A STUDY ON VULNERABILITY TO AGRICULTURE IN KOSI REGION OF BIHAR



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Sabour – 813 210, Bhagalpur, Bihar, India

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VISIT...

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*Dedicated
To
My Parents
&
Sisters*

*Whose perpetual
Affection Inspired Me for Higher Ambitions
in Life*

Jyoti.....✍



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ABSTRACT

Climate is the primary determinant of agricultural productivity. Climate change and its impacts are well recognised today and it will affect either physical or biological system. Bihar is highly vulnerable to climate change and variability because vulnerability to climate change is closely related to poverty as the poor are least able to respond to climate change. To cope up with changes in the production system and virtual stagnation of the crop yield the present study on vulnerability to agriculture in Kosi region of Bihar was planned to examine the factors affecting vulnerability and their relationship. The study was also planned to construct vulnerability index and compare different districts of the delineated area in relation to vulnerability index. For this purpose a composite vulnerability index was developed, emphasizing on the three major components namely, (i) Exposure (ii) Sensitivity and (iii) Adaptive capacity. To derive the vulnerability index and draw meaningful inferences both the method of equal and unequal weight were employed. The four major factors of vulnerability were also taken into consideration to assess the temporal and spatial vulnerability. This includes the demographic factors, climatic factors, agricultural factors and occupational factors. Quantitative assessment of vulnerability is usually done by

constructing 'vulnerability index'. To construct and compare the vulnerability indices the period from 1976-2015 was subdivided into 4 parts i.e. from 1976-1985, 1986-1995, 1996-2005 and 2006-2015. It means spatial as well as temporal vulnerability was also quantified. For the construction of vulnerability index, simple average score method, Patnaik and Narayanan Method by giving equal weight towards the variable. However, Iyengar and Sudarsan's method and Expert judgement method was also used to construct the vulnerability indices. Next two methods were mainly based on giving unequal weight towards the indicators. It is because some parameters influenced more to the vulnerability and vice-versa. For identification of indicators as well as their relationship between them trend and pattern of different factors like agriculture, climatic, demographic and occupational factors of eight districts were undertaken for the same and result revealed that those factors falling under sensitive were positively related, however the factors responsible for adaptive capacity were negatively related with vulnerability. The results of investigation revealed that, in the year 1976-1985 the district of Kishanganj ranked first and the district of Araria ranked last (8th) in the overall vulnerability to climate change. As for contribution of sources was concerned, the agricultural sector played a significant role in ranking Kishanganj district at the first position by contributing to the tune 34.67 per cent to the overall vulnerability followed by occupational 28.96 per cent, climatic 22.45 per cent, and demographic factors 13.92 per cent. From the period 1986-1995, the district of Kishanganj ranked first in the overall vulnerability to climate change amongst all the selected districts of the region replacing Khagaria district to the second position, followed by Purnea district at the third. In the year 1996-2005, Khagaria district retained its first position with demographic and agricultural indicators being major contributors towards the overall vulnerability to climate change. The values of vulnerability indices varied from 0.30 (Madhepura) to 0.59 (Kishanganj) in 1996-2005 indicating that there was a wide variability in the factors influencing climate change. In the year 2006-2015, the district of Supaul replaced Kishanganj from the first position with reference to overall vulnerability to climate change. Data pertaining to sensitivity component was concerned, that due to reoccurrences of flood leads to damage to the crops or livestock population was found maximum in Kishanganj (21.954) district followed by Araria (21.896) and Purnea (20.882). It implies that Kishanganj was remain stand in first position with respect to sensitivity component of vulnerability was concerned. On the basis of the degree of vulnerability the Kishanganj

district was again placed under highly vulnerable district, however the district of Supaul, Saharsa, Madhepura, Purnea and Khagaria were placed under moderate vulnerability whose degree of vulnerability varied from 28.42-73.14 and the district of Araria was considered as least vulnerable district amongst all the selected district under study so far. Its range of vulnerability was varied from ≤ 28.58 . Therefore climate change policies have to be integrated with sustainable development strategy such as social control, pollution control, as well as emphasis towards regional crop planning for most vulnerable district of Kosi region of Bihar. Since the worst sufferers of climate change impacts are the rural communities, (who depends mainly on agriculture as their livelihoods), it is important to focus on the impacts of climate change on livelihoods, and re-establish the links among poverty, livelihood and environment. However, focusing on the communities only are not enough, and so long as the community initiatives do not become part of the government policies, it is difficult to sustain the efforts. Thus, the link between local, state and national governments to the community is of utmost importance.

Dr. Meera Kumari

Jyoti Bharti



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LIST OF ABBREVIATIONS

°C	: Degree Centigrade
<i>i.e.</i>	: That is
kg	: Kilogram
ha	: Hectare
cm	: Centimeter
No.	: number
g	: Gram
Fig.	: Figure
m²	: Meter square
MT	: Metric Tonnes
@	: At the rate
<i>et.al</i>	: etalii(Co-authors)
mm	: Mili meter
P	Period
Vul	: Vulnerability
POP	: Population
Demo	: Demographic
Occ	: Occupational
Agril	: Agricultural
Km	: Kilometer
ht.	: Height
wt.	: Weight
GDP	: Gross domestic Product
ppm	: Parts per million
Max	: Maximum
Min	: Minimum
Agril.	: agricultural
IMR	: Infant mortality rate

INTRODUCTION

Bihar is one of the most disaster prone states of the country. Floods, droughts, earthquakes, heat/cold waves, river erosions, fire incidence etc. are various forms of disasters prevalent in the state. Among natural disasters, flood is the most common and a regular annual phenomenon in Bihar resulting in enormous loss of life and property. In addition to floods, the seismic vulnerability of the State to earthquakes is another constant danger. Increasing population pressure, high density of buildings and their poor construction quality, the settlement in vulnerable areas and inadequate or no investment on mitigation / preparedness measures has further increased the vulnerability of the population to these natural hazards. In addition to extensive damage to life and property, these disasters over the years have also adversely affected economic development in the State (Bihar flood report 2007). The plains of north Bihar are some of the most susceptible areas in India, prone to flooding. A review by Kale (1997) indicated that the plains of north Bihar have recorded the highest number of floods during the last 30 years. The total area affected by floods has also increased during these years. Drained by two major rivers, the Kosi and Gandak, and several smaller systems such as Burhi Gandak, Baghmata and Kamla-Balan, the plains of north Bihar have experienced extensive and frequent loss of life and property over the last several decades (Sinha and Jain, 1998). The Kosi River (*The Sorrow of Bihar*) is well known in India for rapid and frequent avulsions of its course and the extensive flood damages it causes almost every year. The Kosi is one of the major tributaries of the Ganga River, and rises in the Nepal Himalayas.

With growing recognition of climate change and clear evidences of observed changes in climate during 20th century, an increasing emphasis on food security and its regional impacts has come to forefront of the scientific community. Most of the simulation studies have indicated that the direct impacts of climate changes would be small on *kharif* crops but *kharif* agriculture will become vulnerable due to increased incidence of weather extremes such as decline of rainy days and rainfall intensity, increase in duration and frequency of drought and floods, diurnal asymmetry of temperature, change in humidity, and increase in pest incidence and virulence. *Rabi* crop production may become comparatively more vulnerable due to increase in

temperature, asymmetry of day and night temperature and higher uncertainties in rainfall. The impacts of the climate change on Indian agriculture would be small in near future, but in long run the Indian agriculture may be seriously affected depending upon season, level of management, and magnitude of climate change (Mall et. al., 2006)

Climate change and its impacts are well recognised today and it will affect either physical or biological system. Climate is the primary determinant of agricultural productivity. Climate Change Impacts has multi-dimensional effect on humanities in terms of several socio-economic parameters like agriculture, human health and sea level rise. Bihar is highly vulnerable to climate change and variability because vulnerability to climate change is closely related to poverty as the poor are least able to respond to climate change. To cope up with changes in the production system virtual stagnation of the crop yield. Climate change may affect agriculture and consequently the livelihoods of people due to changes in temperature, precipitation, soil moisture, soil fertility, the length of the growing season, an increase in the probability of extreme events such as droughts, extreme heat waves, heavy rainfall, cyclones, flooding of the coastal areas, erosion etc.

The word ‘vulnerability’ is generally associated with natural hazards such as floods, droughts, and social hazards like poverty, etc. It is extensively used in climate change literature to denote the extent of damage by which a region is expected to be affected. There are a large number of studies on vulnerability that have been carried out in the context of climate change – the definition of vulnerability tends to vary according to the perception of the particular researcher. A brief review of various definitions is given below. Chamber (1983) defined that vulnerability has two sides. One is an external side of risks, shocks to which can subject an individual or household to climate change; there is also an internal side, which alludes to defencelessness, meaning a lack of means to cope without damaging loss. Blaikie et al. (1994) defined vulnerability as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of natural hazards and states that vulnerability can be viewed along a continuum from resilience to susceptibility. According to Adger (1999) vulnerability is the extent to which a natural or social system is susceptible to sustaining damage from climate change

Vulnerability' is usually associated with natural hazards like floods, droughts, and socio hazards like poverty etc. However, with increased importance in climate change research, it has been widely used to compute vulnerability. The Intergovernmental Panel on climate change (IPCC) has defined vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (McCarthy et al., 2001). Vulnerability has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk" (Liverman, 1990).

In the developing countries like India, the small and marginal farmers, in particular, are more vulnerable to both to the current and future climate change impacts, given their high dependence on agriculture, strong reliance on ecosystem and rapid population growth. Year to year variability in climate contributes to rural poverty where the exposure is high and adaptive capacity is low. The effects of climatic variability on farming is prominent as witnessed by delayed sowing, changes in cropping patterns, higher evidence of pest and diseases, frequent and persistent droughts, less availability of water in tanks and canals for irrigation, reduced profits due to increased prices of inputs and wages as well as stagnation of output prices, shift towards non-farm occupations, migration, asset disinvestment etc. Most climate change models predict that the damages will adversely affect the small farmers, especially in the rainfed areas.

Vulnerability captures notions of possible loss, damage, and impact of threat risk and stress of uncertainty and insecurity of a lack of power and control; and of a number of other factors that contribute to a feeling or state of being vulnerable. Climate change is the biggest threat to livelihood sustainability of our times, posing an imminent danger to human security and the development of human capabilities. The destruction of agriculture and infrastructure has been observed by climate variability (like droughts and floods) which has a negative impact on human health and livelihood security. The rural people are particularly vulnerable to climate variability and changes owing to their heavy dependence on agriculture for food and livelihood. For preparing people to face these challenges, decision-makers and policy planners need information on climate change. A close assessment of the vulnerability i.e., the degree to which agriculture is susceptible to the adverse effects of climate

change, including climate variability and extremes is needed to allocate resources effectively and reduce the impacts. Vulnerability is often reflected in the condition of the economic system as well as the socio-economic characteristics of the population living in that system. Until recently the centre of attention has been on the actual or potential impact of climatic change and mitigation options. Adaptation is a vital part of a response to the challenge of climate change. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity. Thus, vulnerability has three components: exposure, sensitivity and adaptive capacity. These three components are described as follows:

1. Exposure can be interpreted as the direct danger (i.e., the stressor) and the nature and extent of changes to a region's climate variables (e.g. temperature, precipitation, extreme weather events)
2. Sensitivity describes the human-environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact.
3. Adaptive capacity represents the potential to implement adaptation measures that help avert potential impacts.

Due to its adverse impacts, climate change has always been a matter of great concern to the farming, scientific and developmental communities. Climatic extreme events together with an increase in rates of change in climatic parameters could affect various sectors including water, agriculture, health, tourism, transport, energy and the like. The climate change is one of the greatest challenges humanity faces and/or will be facing, and it is considered the world's most vulnerable population who are immediately at risk. The most vulnerable groups are the poor in our countries where high levels of poverty, lack of social safety nets and access to education and healthcare have increased their vulnerability to climatic change. (HDI Report 2008)

Even though everyone is potentially affected by climate change, the poor in the developing world are more likely to suffer a disproportionate share of the impacts of climate change induced extreme events. In the future, the climate change associated impacts are imminent with the anticipated vagaries of the weather. The impacts of climate change would add an additional burden to the poor smallholder farmers of

semi-arid tropics of India. The region is already hapless, with low soil productivity, rainfall variability, water shortage or scarcity, and poor development in rural infrastructure, institutions and markets being major identified characteristics of the semi-arid tropics (Shiferaw and Bantilan, 2004; Bantilan and Keatinge, 2007).

1.1 Importance of study in Bihar

Bihar is India's most flood-prone State, with 76 % of the population, in the north Bihar living under the recurring threat of flood devastation. About 68800 sq Km. out of total geographical area of 94160 sq Km. comprising 73.06% is flood affected. Bihar has experienced extensive and frequent loss of life and property over the last several decades (Sinha and Jain, 1998). The flood affected areas of Bihar in zone 2, consists of 8 districts out of 36 districts in the State. The worst affected districts were Saharsa, Supaul, Katihar, Purnia, Madhepura, Khagaria, Araria and Kishanganj. The Damage caused due to flood are roughly 5-6 million of families in 20 districts damaged 5.12 lakhs houses and estimated crop losses was about 1.64 million ha leading to a loss of the value of about Rs 113.6 billion. This study has been planned keeping in view the extent of damage due to natural calamities' which is most important component of vulnerability and on such events no study has been carried out so far in our state. This one of the important researchable issues especially for Northern part of Bihar. Therefore with this backdrop the study has been planned with these following objectives.

1.2 Objectives

1. To identify different climatic and socio-economic indicators of vulnerability.
2. To examine the relative influence of different climatic and socio-economic factors on level of vulnerability in the study area.
3. To compare different districts of the delineated area in relation to vulnerability index.
4. To suggest policy measure to develop adaptive capacity to cope with vulnerability

1.3 Limitation of the Study

A well thought and designed research methodology may not be free from limitations, hence present methodology adopted for analyzing data in the present investigation may have inherent limitations. The main limitations of the present study are as follows:

- The study is totally based on secondary data at district level and getting appropriate district-wise data was indeed difficult task.
- The study is conducted at koshi region including 8 districts of Bihar state and the finding may not justify the overall scenario of state.
- Whole study was based on the secondary data and collected from published sources which may contain errors.

1.4 Plan of the Thesis

The thesis has been divided into six chapters. **Chapter I** deals with the identification of the problems, specific objectives of the research, its importance and limitations of the study. A comprehensive review of relevant studies of the problems is presented in **Chapter II**. **Chapter III** discusses the design of study, method of data collection and methods of analysis adopted in the study. Brief project area is presented in **Chapter IV**. The results or findings through appropriate discussion of study are presented in the penultimate **Chapter V**. The final **Chapter VI** gives a summary of the study and conclusions followed by **References**.



REVIEW OF LITERATURE

This chapter presents a review of the past studies undertaken by various economists, research workers, and organizations relating to the current research topic for enhancing better understanding of the study. A review of past research helps in identifying the conceptual and methodological issues relevant to the study. This will enable the researcher to identify the gaps, collect relevant data and subject them to sound reasoning and meaningful interpretation. Keeping in view the available literature has been carefully examined and meticulously summarized and have been presented under the following heads for the sake of simplicity.

2.1 Concept, meaning and definitions of vulnerability

2.2 Linking climate change and vulnerability

2.3 Identifying key factors affecting vulnerability

2.4 Assessment of vulnerability

2.5 Relationships between vulnerability and adaptive capacity

2.6 Policy measures to counter climatic vulnerability

2.1 Concept, meaning and definitions of vulnerability

The term ‘vulnerability’ has its roots in geography and natural hazards research but now a days it becomes the central concept in climate change research as well as in a number of other research contexts. The concept is equally emphasized by various research communities such as those dealing with disaster management, public health, development, secure livelihoods, and climate impact and adaptation and conceptualized in many different ways. For instance, natural scientists tend to apply the term in a descriptive manner whereas social scientists tend to use it in the context of a specific explanatory model. Therefore, widespread disagreement about the appropriate definition of vulnerability is a frequent cause for misunderstanding in interdisciplinary research on vulnerability and adaptation to climate change. To ameliorate this confusion, a comprehensive and consistent conceptual framework of vulnerability that combines a terminology of vulnerable situations, a classification

scheme for vulnerability factors, and a terminology of vulnerability concepts are required.

Timmermann (1981) posited that “vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern”.

Morgan (1981) regarded vulnerability as some measure of the impact of a hazard on human socio-economic systems, which suggests that we ought to explore vulnerability in the context of a framework where the hazard process can be represented, and its impacts and relationship to the characteristics of the system can be modelled.

Liverman (1990) noted that vulnerability “has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk”. Exposure, sensitivity, coping capacity, criticality and robustness could easily be added to this list.

The existence of competing conceptualizations and terminologies of vulnerability has become particularly problematic in the context of anthropogenic climate change. The cross-cutting nature of the global climate problem requires the intense collaboration of scholars from different research traditions, such as climate science, disaster management, risk assessment, development, economics, and policy analysis. This collaboration must be based on a consistent terminology that facilitates researchers from different traditions to communicate clearly and transparently despite differences in the conceptual models applied (**Laroui and van der Zwaan, 2001**).

McCarthy *et al.* (2001) defined ‘vulnerability’ as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.”

Brooks (2003) suggests that one can only talk meaningfully about the vulnerability of a specified system to a specified hazard or range of hazards", and to distinguish between current and future vulnerability.

Luers *et al.* (2003) argued that vulnerability assessments should shift away from attempting to quantify the vulnerability of a place and focus instead on assessing the vulnerability of selected variables of concern and to specific sets of stressors".

The ordinary use of the word 'vulnerability' refers to the capacity to be wounded, i.e., the degree to which a system is likely to experience harm due to exposure to a hazard (**Turner II *et al.*, 2003**).

Downing and Patwardhan (2004) presented a formal nomenclature for the vulnerability of social systems that includes the threat, the region, the sector, the population group, the consequence, and the time period

Fussel (2004) described climate-related vulnerability assessments based on the characteristics of the vulnerable system, the type and number of stressors and their root causes, their effects on the system, and the time horizon of the assessment.

Metzger *et al.* (2005) specifies the vulnerability of ecosystems to global change with respect to a particular ecosystem service, a location, a scenario of stressors, and a time slice.

Vulnerability represents a conceptual cluster" for integrative human-environment research in the sense of (**Newell *et al.*, 2005**). The existence of competing conceptualizations and terminologies of vulnerability has become particularly problematic in climate change research, which is characterized by intense collaboration between scholars from many different research traditions, including climate science, risk assessment, development, economics, and policy analysis. This collaboration must be based on a consistent terminology that facilitates researchers from different traditions to communicate clearly and transparently despite differences in the conceptual models applied.

The above frameworks largely agree that the following four dimensions are fundamental to describe a vulnerable situation.

System: The system of analysis, such as a coupled human-environment system, a population group, an economic sector, a geographical region, or a natural system. Note that some research traditions do restrict the concept of vulnerability to social systems or coupled human-environment systems whereas others apply it to any system that is potentially threatened by a hazard (**McCarthy *et al.*, 2001**).

Attribute of concern: The valued attribute(s) of the vulnerable system that is/are threatened by its exposure to a hazard. Examples of attributes of concern include human lives and health, the existence, income and cultural identity of a community, and the biodiversity, carbon sequestration potential and timber productivity of a forest ecosystem.

Hazard: **United Nations (2004)** define 'hazard' broadly as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation". Hence, a hazard is understood as some influence that may adversely affect a valued attribute of a system. A hazard is generally but not always external to the system under consideration. For instance, a community may also be threatened by hazardous business activities or by unsustainable land management practices within this community. Hazards are often distinguished into discrete hazards, denoted as perturbations, and continuous hazards, denoted as stress or stressor.

Temporal reference: The point in time or time period of interest. Specifying a temporal reference is particularly important when the risk to a system is expected to change significantly during the time horizon of a vulnerability assessment, such as for long-term assessments of anthropogenic climate change.

These four attributes allow characterizing a vulnerable situation independent of a particular research tradition. I propose the following nomenclature to fully describe a vulnerable situation: vulnerability of a system's attribute(s) of concern to a hazard (in temporal reference). The temporal reference can alternatively be stated as the first qualifier. Examples for fully qualified descriptions of vulnerability are "current vulnerability of smallholder agriculturalists in a specific region at risk of starvation to drought" (**Downing and Patwardhan, 2004**), "vulnerability of the tourism sector in a specific mountain region to climate change over the next 30 years", and "vulnerability of a particular ecosystem's net primary production to wild fires in 2050". Note that this nomenclature of vulnerability is also applicable to related concepts such as 'adaptive capacity' and 'risk'.

Patwardhan (2006) described vulnerability as a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

The concept of "vulnerability" has important communicative value: it describes in a powerful way that change is not always for the good. Vulnerability captures notions of possible loss, damage, and impact; of threat, risk, and stress; of uncertainty and insecurity; of a lack of power and control; and of a number of other factors that contribute to a feeling or state of being vulnerable (**Fussel, 2006**).

2.2 Linking climate change and vulnerability

The last two decades have witnessed extensive research on potential and observed impacts of climate change on all kinds of natural and social systems, as reviewed by **McCarthy *et al.*, 2001**. This research has been conducted to advance scientific knowledge and to support the formulation and implementation of policies that limit adverse impacts of climate change and variability on environmental and human systems. This study reviews the evolution of approaches for assessing vulnerability to climate change.

Kohnle and Gauckler (2003) evaluated the impact of the storm called Lothar in December 1999 on a forest district in the periphery of the area of major damage in south-western Germany. The evaluation was based on timber salvage data of four publicly owned forests, on inventory data gathered for all stands during a survey in the summer of 1999, and for selected stands in spring 2000. Based on the growing stock prior to the storm and the volume of salvage (post the storm), the vulnerability of spruce was ranked highest followed by beech, oak and ash/sycamore. Apparently, species composition of stands did not mediate vulnerability of spruce: the proportion of standing volume of spruce removed by the storm did not differ significantly between stands of almost pure spruce and mixed stands of spruce and deciduous trees.

Rahmstorf *et al.* (2007) in their study of recent climate change observations, compared the Intergovernmental Panel on Climate Change's (IPCC) projections, found that: 'the data now available raise concerns that the climate system, in particular sea level, may be responding more quickly than climate models indicate' Numerous examples can now be cited of shifts in climate and ecological systems that reflect these recent changes. They include the more rapid melting of Antarctic ice (**Rignot *et al.*, 2008**) and increased hurricane activity (**Saunders and Lea, 2008**). The threat of dangerous 'tipping points' in the global climate system being breached is also increasingly being discussed (**Lenton *et al.*, 2008**). *The Stern Review* highlights the potential economic implications, noting that abrupt and large scale climate change could lead to a 5 to 10% loss of global GDP (**Stern, 2007**).

Richardson *et al.* (2009) emphasized on equity issues and societal transformation to mitigate and adapt to climate change and bring long-term benefits. This is the climate change science and policy arena that faces the adaptation community: while scientific research findings are painting an increasingly challenging picture, the policy community and industry have yet to develop an effective response.

Taken together, these warning signs add urgency to calls to reduce greenhouse gas emissions, while at the same time planning for the challenges and potential opportunities linked to the changing climate.

Extreme weather events exert a huge cost on economies and societies. Building resilience to present day climate variability concerns maintaining the resilience of our society, financial and the natural economy. Research suggests that global mean temperatures are climbing towards 4°C above pre-industrial levels and may go beyond that level, potentially as soon as the 2060s (**Betts *et al.*, 2011**).

2.2.1 Impact on agricultural systems

The agriculture sector in India is already threatened by existing factors such as land use changes, scarcity of water resources, increasing air pollution and loss of biodiversity. In a tropical country such as India, even minimal warming will lead to loss in crop yields (**Parry *et al.*, 2007**). Further studies conducted by the Indian Agricultural Research Institute (IARI) indicate the possibility of loss of 4-5 million tons in wheat production with every rise of 1 degree C temperature throughout the growing period even after considering carbon fertilization. Losses for other crops are still uncertain but are expected to be smaller, especially for kharif crops (**Aggarwal, 2008**).

Research also suggests that erratic monsoons will have serious effects on rain-fed agriculture with projected decreases in the productivity of crops including rice, maize and sorghum (especially in the Western Ghats, Coastal region and North eastern regions), apples (in the Himalayan region) (**Kumar *et al.*, 2011**). Studies indicate that increased droughts and floods are likely to increase production variability and lead to considerable effects on microbes, pathogens, and insects needed for the upkeep of healthy agricultural systems. The **UNFCCC (2007)** have indicated that increasing sea and river water temperatures are likely to affect fish breeding, migration, and harvests. Increasing glacier melt in Himalayas could affect availability of irrigation especially in the Indo-Gangetic plains, which, in turn, would have consequences on food production.

Aggarwal *et al.* (2009) estimated the impact of climate change on livestock and conclude that animal distress could lead to effects on reproduction and subsequently loss of 1.5 million tons of milk by 2020.

Tripathi (2013) assessed the vulnerability to climate change of farmers in Uttar Pradesh (UP). He used 17 environmental and socioeconomic factors to see which districts of UP are the most vulnerable to climate change, and attempts to identify the factors on a set of explanatory variables. The study finds that infrastructurally and economically developed districts are less vulnerable to climate change; in other words, vulnerability to climate change and variability is linked with social and economic development. This observation is corroborated by the findings of relational analysis. In relational analysis, livestock, forestry, consumption of fertiliser, per capita income, and infant mortality rate are observed to be important correlates of farmers' vulnerability to climate change; these should be focussed on. Also, farmers' awareness and adaptive capacity to climate change needs to be strengthened, for which policy options such as crop insurance and early warning systems would help.

2.2.2 Impact on forests and biodiversity

Chaturvedi et al. (2011) developed a vulnerability map and projected the impact of climate change on Indian forests and conclude that 39% and 35% of the forests grids in India will likely undergo change under the A2 and B2 scenarios respectively. The vulnerability map suggests that the concentration of vulnerable forest grid is higher in the upper Himalayan stretches, parts of central India, northern Western Ghats and Eastern Ghats. The upper Himalayan stretches and parts of central India currently have low development indicators, so that they will struggle to cope with any impacts they might be faced with.

The forests of northeast, southern Western Ghats and eastern parts of India are projected to be least vulnerable. This is on account of their high biodiversity, low fragmentation, high tree density as well as low rates of vegetation change (as these regions experience lower levels of temperature increase and gain substantially in terms of precipitation). **Chaturvedi et al. (2011)** suggest that low vegetation vulnerability in North-eastern India means these regions are suitable especially for forest conservation projects.

2.3.2 Impact on infrastructure systems

In India, investments worth US\$ 120 billion have been planned for infrastructure asset creation during 2011-2012 (**Naswa and Garg, 2011**) Climate change induced natural disasters could put serious pressure on these investments. The

critical climate parameters of temperature, precipitation, sea-level rise and extreme events pose direct and indirect threats to India's infrastructure assets. Enhanced landslides, vegetation cover, excessive siltation in rivers, and soil erosion could be direct impacts. Groundwater table depletion, energy demand changes, and migratory traffic could be the possible indirect impacts. The risks could be physical, technological, supply-chain or regulatory in nature (**Naswa and Garg, 2011**). A study on the adverse impact of climate change on the Konkan Railways (a 760 kilometre line connecting Maharashtra, Goa and Karnataka – a region of criss-crossing rivers, deep valleys and mountains) leading to both direct and indirect risks in the railway sector has indicated key impacts such as infrastructure damages, disruption to services, repair and reconstruction costs, changes in both agricultural freight traffic and passenger traffic as a result of climate change. For instance, the study identified that 20% of repair and maintenance expenses on tracks, tunnels and bridges were due to climatic reasons (**Gachui et al., 2007**).

2.3 Identifying key factors affecting vulnerability

A clear description of the vulnerable situation is an important first step for avoiding misunderstandings around vulnerability. However, there are also different interpretations of the term 'vulnerability' itself. These different vulnerability concepts can be distinguished by the vulnerability factors that they consider.

Vulnerability depends critically on context, and the factors that make a system vulnerable to a hazard will depend on the nature of the system and the type of hazard in question. The factors that make a rural community in semi-arid Africa vulnerable to drought will not be identical to those that make areas of a wealthy industrialised nation such as Norway vulnerable to flooding, wind storms and other extreme weather events. Isolation and income diversity might be important determinants of vulnerability to drought for rural communities in Africa, whereas the dominant factors mediating vulnerability to storms and floods in Norway might be the quality of physical infrastructure and the efficacy of land use planning. Nonetheless, there are certain factors that are likely to influence vulnerability to a wide variety of hazards in different geographical and socio-political contexts. These are developmental factors including poverty, health status, economic inequality and elements of governance, to name but a few. These may be referred to as generic determinants of vulnerability, as opposed to specific determinants relevant to a particular context and hazard type, such

as the price of a particular food crop, the number of storm shelters available for the use of a coastal community, or the existence of regulations concerning the robustness of buildings. Although the relative importance of different generic factors will exhibit some variation, such factors may be viewed as the foundation on which specific measures for reducing vulnerability and facilitation adaptation are built. For example, a rural community is more likely to be serviced by transport infrastructure if it is effectively represented at the political level. Building codes are more likely to be enforced if corruption in the building industry and regulatory agencies is minimised.

Several researchers distinguish biophysical (or natural) vulnerability from social (or socioeconomic) vulnerability. However, there is no agreement on the meaning of these terms. The conceptual framework for coastal vulnerability assessment developed by **Klein and Nicholls (1999)** sees 'natural vulnerability' as one of the determinants of 'socioeconomic vulnerability'. **Cutter (1996)**, in contrast, regards the 'biophysical' and the 'social' dimension of vulnerability as independent. According to the terminology proposed by **Brooks (2003)**, finally, "social vulnerability may be viewed as one of the determinants of biophysical vulnerability".

Intergovernmental Panel on Climate Change (IPCC), links vulnerability with climatic change, and point out that the vulnerability of a region depends to a great extent on its wealth and that poverty limits adaptive capabilities (**IPCC, 2000**). Further, they argue that socio-economic systems "typically are more vulnerable in developing countries where economic and institutional circumstances are less favourable". Also a common theme in the climate change impacts and vulnerability literature is the idea that countries, regions, economic sectors and social groups differ in their degree of vulnerability to climate change (**Bohle et.al., 1994**). This is due partly to the fact that changes in climatic patterns are uneven and are also not evenly distributed around the globe. Though vulnerability differs substantially across regions, it is recognized that "even within regions... impacts, adaptive capacity and vulnerability will vary" (**IPCC, 2001**).

The glossary of the TAR (**IPCC, 2001**) defines vulnerability as "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Thus, vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." However, **Smit et al. (2001)** in the IPCC TAR, citing **Smit et al. (1999)**, described vulnerability as the "degree to which a

system is susceptible to injury, damage, or harm (one part—the problematic or detrimental part—of sensitivity)”. Sensitivity in turn is described as the “degree to which a system is affected by or responsive to climate stimuli”.

Moss *et al.* (2001) identified three dimensions of vulnerability to climate change. The physical-environmental dimension accounts for the harm caused by climate". It refers to the climatic conditions in a region and to the biophysical impacts of climate change, such as changes in agricultural productivity or the distribution of disease vectors. The socioeconomic dimension refers to “a region's capacity to recover from extreme events and adapt to change over the longer term". The third dimension, external assistance, is defined as “the degree to which a region may be assisted in its attempts to adapt to change through its allies and trading partners, diasporic communities in other regions, and international arrangements to provide aid". In contrast to **United Nations (2004)**, this conceptualization of vulnerability includes factors outside the vulnerable system, such as characteristics of the stressor and the expected level of external assistance.

United Nations (2004) distinguish four groups of vulnerability factors that are relevant in the context of disaster reduction: physical factors, which describe the exposure of vulnerable elements within a region; economic factors, which describe the economic resources of individuals, populations groups, and communities; social factors, which describe non-economic factors that determine the well-being of individuals, populations groups, and communities, such as the level of education, security, access to basic human rights, and good governance; and environmental factors, which describe the state of the environment within a region. All of these factors describe properties of the vulnerable system or community rather than of the external stressors.

Brooks *et al.* (2005) presented a set of indicators of vulnerability and capacity to adapt to climate variability, and by extension climate change, derived using a novel empirical analysis of data aggregated at the national level on a decadal timescale. The analysis is based on a conceptual framework in which risk is viewed in terms of outcome, and is a function of physically defined climate hazards and socially constructed vulnerability. Climate outcomes are represented by mortality from climate-related disasters, using the emergency events data base data set, statistical relationships between mortality and a shortlist of potential proxies for vulnerability are used to identify key vulnerability indicators. We find that 11 key indicators exhibit

a strong relationship with decadal aggregated mortality associated with climate-related disasters. Validation of indicators, relationships between vulnerability and adaptive capacity, and the sensitivity of subsequent vulnerability assessments to different sets of weightings are explored using expert judgement data, collected through a focus group exercise. The data are used to provide a robust assessment of vulnerability to climate-related mortality at the national level, and represent an entry point to more detailed explorations of vulnerability and adaptive capacity. They indicate that the most vulnerable nations are those situated in sub-Saharan Africa and those that have recently experienced conflict. Adaptive capacity—one element of vulnerability—is associated predominantly with governance, civil and political rights, and literacy.

Pandey *et al.* (2007) analysed the data from Kalahandi and Nuapada districts of Orissa (India) revealed that (a) droughts in this region occurred with a frequency of once in every 3 to 4 years, (b) droughts occurred in the year when the ratio of annual rainfall to potential evapo-transpiration (Pae/PET) was less than 0.6, (c) EDI better represented the droughts in the area than any other index; (d) all SPI, EDI and annual deviation from the mean showed a similar trend of drought severity. The comparison of all indices and results of analysis led to several useful and pragmatic inferences in understanding the drought attributes of the study area.

Guiteras (2007) estimated the economic impact of climate change on Indian agriculture using a 40-year district-level panel data set covering over 200 Indian districts. These panel estimates incorporate farmers' within-year adaptations to annual weather shocks. He argued that these estimates, derived from short-run weather effects, are also relevant for predicting the medium-run economic impact of climate change if farmers are constrained in their ability to recognize and adapt quickly to changing mean climate. The predicted medium-run impact is negative and statistically significant: I find that projected climate change over the period 2010-2039 reduces major crop yields by 4.5 to nine percent. The long-run (2070-2099) impact is dramatic, reducing yields by 25 percent or more in the absence of long-run adaptation. These results suggest that climate change is likely to impose significant costs on the Indian economy unless farmers can quickly recognize and adapt to increasing temperatures. Such rapid adaptation may be less plausible in a developing country, where access to information and capital is limited.

The massive Kosi River floods of August 2008 caused unprecedented loss to lives, livelihoods, infrastructure and property in north-eastern Bihar. Although floods have been a recurring feature in parts of the state, the 2008 floods were not usual. The Kosi burst its embankments and changed course, inundating areas of Bihar that had not experienced such flooding for half a century. About 1,000 villages in five districts (*Araria, Madhepura, Purnia, Saharsa and Supaul*) were affected, involving three million people, of whom about one million were evacuated. The estimated loss was amounting around Rs. 1960 crore (**UNDP, 2009**).

Fundamental research on extreme events, nonlinear impacts and tipping points needs to be extended beyond physical climate systems to biological, social and economic systems (**Berkes, 2007**), such as the effects of world food crises and financial crises on adaptive capacity. More diagnostic studies (**Peterson and Manton, 2008**) of exposure and vulnerability to climate extremes and their related socio-economic, demographic and cultural factors are also important (**Russill and Nyssa, 2009**). These studies can contribute to understanding societal vulnerability to climate variability and extreme events today as well as how this may change under changing climate conditions. Finally, more research should focus on how to effectively mobilize and conduct rapid scientific assessment both for short-term policy decisions and long-term understanding when extreme events occur (**UNEP, 2013**).

Gosain et al. (2011) projected the impact of climate change on the 17 most important river basins in India up to mid-century and towards the end of the century. They estimated a decline in rainfall in 14 out of the 17 river basins towards the 2030s (mid century) and the 2080s (end century). In almost all river basins rainfall declines from 4% to 23%, following changes in precipitation. As a result of the decline in basin level rainfall, water yield in most of the river basins will decline by the 2030s and almost all (except the Krishna and Cauvery basins) by the 2080s.

Kriegler et al. (2012) explored that a more consistent use of socio-economic scenarios would allow an integrated perspective on mitigation, adaptation and residual climate impacts remains a major challenge. They asserted that the identification of a set of global narratives and socio-economic pathways offering scalability to different regional contexts, a reasonable coverage of key socio-economic dimensions and relevant futures, and a sophisticated approach to separating climate policy from counter-factual “no policy” scenarios would be an important step toward meeting

this challenge. To this end, we introduce the concept of “shared socio-economic (reference) pathways”. Sufficient coverage of the relevant socio-economic dimensions may be achieved by locating the pathways along the dimensions of challenges to mitigation and to adaptation. The pathways should be specified in an iterative manner and with close collaboration between integrated assessment modelers and impact, adaptation and vulnerability researchers to assure coverage of key dimensions, sufficient scalability and widespread adoption. They can be used not only as inputs to analyses, but also to collect the results of different climate change analyses in a matrix defined by two dimensions: climate exposure as characterized by a radiative forcing or temperature level and socio-economic development as classified by the pathways. For some applications, socio-economic pathways may have to be augmented by “shared climate policy assumptions” capturing global components of climate policies that some studies may require as inputs. They concluded that the development of shared socio-economic (reference) pathways, and integrated socio-economic scenarios more broadly, is a useful focal point for collaborative efforts between integrated assessment and impact, adaptation and vulnerability researchers.

Chaturvedi *et al.* (2014) emphasized on temperature variability, precipitation variability, rising sea-levels, extreme events (drought and flooding), and risk to environmental health to demonstrate the impact of climate change in India.

Gizachew and Shimelis (2014) developed a biophysical and socio-economic indicator based integrated vulnerability assessment technique to map climate change vulnerability. Indicators were generated and analysed under three components of vulnerability, namely exposure, sensitivity and adaptive capacity; and finally aggregated into a single vulnerability index. The values of all indicators were normalised by considering their functional relationship with vulnerability, and expert judgment was then used to assign weights to all indicators. Aggregate vulnerability index (VI) was finally determined from the weighted sum of all indicators and mapped over the 16 districts in Central Rift Valley (CRV) of Ethiopia. This study shows that vulnerability mapping is crucial in determining the varying degrees of vulnerability of different localities, and generating information that can help researchers, policy makers, private and public institutions in formulating site-specific adaptation strategies and prioritising adaptation investments to the most vulnerable hotspots.

2.4 Assessment of vulnerability

The diversity of interpretations and concepts of vulnerability results in a variety of methodological approaches and tools that have evolved to assess it, which is also reflected in a vast variety of conducted vulnerability assessments with regard to the agricultural sector. Climate change vulnerability assessments can, for example, vary with respect to the methodological approach (e.g. experimental, modelling, meta-analysis, survey-based), the integration of natural and social science, policy focus, time horizon (short- to long-term), spatial scale (farm, local, national, regional, global level), consideration of uncertainties, and the degree of stakeholder involvement. In this section, general methods applied for assessing vulnerability to climate change are highlighted, focusing briefly on the use of indicators, modelling approaches and stakeholder involvement. Thus, the methods outlined in these sections are illustrative rather than exhaustive.

2.4.1 Choice of vulnerability indicators and indices

The literature provides a vast variety of definitions for vulnerability, mostly depending on the disciplines of their origin (**Adger, 2006**). **Nelson et al. (2010)** pointed out that definitions of vulnerability should not be confused with conceptual frameworks. While definitions describe the components of vulnerability, conceptual frameworks give meaning to the definitions so that they can be analysed according to the analytical context in a transparent and repeatable way (**Nelson et al., 2010**). However, it is essential first to clarify and understand what is meant when vulnerability is spoken and written about in the climate change context (**Eakin and Luers, 2006; Janssen and Ostrom, 2006**). A consistent and transparent terminology helps to facilitate the collaboration between different researchers and stakeholders, even if there are differences in the conceptual models applied (**Downing and Patwardhan, 2005; Füssel, 2007; cf. Laroui and van der Zwaan, 2001; Newell et al., 2005**).

A common method to quantify vulnerability to climate change is by using a set or composite of proxy indicators. Indicators can, for example, be used to link biophysical and economic attributes of systems to vulnerability outcomes via a quantitative function (e.g. decline in yield, resource quality, land value or economic returns). However, identifying and constructing appropriate indicators for vulnerability assessments is highly challenging (**Downing et al., 2001; OECD, 2008**).

Following the IPCC definition of vulnerability to climate change, measures of vulnerability typically include the three components of climate change, i.e. exposure to climate change, sensitivity to its effects, and adaptive capacity to cope with the effects. Vulnerability assessments, therefore, typically attempt to quantify the three components by identifying appropriate indicators and combining them into indices for each. Subsequently, the components are then often combined into an integrated index of vulnerability. The indicators used for the components include usually both biophysical (primarily for exposure and sensitivity) and socio-economic (mainly for adaptive capacity) sources (Yohe and Tol, 2002; Adger *et al.*, 2004; Schröter *et al.*, 2005; Metzger and Schröter, 2005; Eakin and Luers, 2006; Gbetibouo, Ringler and Hassan, 2010; cf. Iglesias, Quiroga and Diz, 2011).

Impacts of climate variability and change can generally be described quantitatively by changes in biophysical indicators (e.g. agricultural productivity with regard to crop yields) or by socio-economic indicators (e.g. agricultural income from crop production). However, while there are agreed indicators to measure the *impact* of climate change, there seem to exist no agreed metrics to describe *vulnerability* (e.g. of crop yields or agricultural income). This seems to be the case because vulnerability is rather a relative measure than something that can be expressed in absolute terms (Adger, 2006; Füssel and Klein, 2006; Eriksen and Kelly, 2007; Füssel, 2009; Hinkel, 2011). Consequently it is argued, that: (i) an indicator can generally only describe a measure of relative vulnerability (between places or time periods); and (ii) individual indicators are not able to portray the heterogeneity of vulnerability (especially with regard to socio-economic vulnerability). Hinkel (2011) therefore argues that a “one size fits all” vulnerability label is not sufficient as it disguises the vast amount of different types of problems addressed and methods applied. Thus, rather than using the term vulnerability as an unspecific proxy, it is important to use an explicit terminology in order to clarify which particular vulnerability problems are addressed and which methodologies are applied (Füssel, 2009; Klein, 2009; Hinkel, 2011).

As discussed in previous sections, vulnerability is place-based and context-specific and consequently the significance of particular indicators can vary from region to region, especially depending on the specific socio-economic context. Consequently, at local scales and when systems can be narrowly defined, vulnerability indicators are considered to be a suitable means to identify particularly

vulnerable people, regions or sectors (**Barnett, Lambert and Fry, 2008; Hinkel, 2011**). Conversely, attempts to rank and compare vulnerability across regions or countries via indicator values, mainly with the aim to assist governmental bodies or organizations in the allocation of resources to reduce vulnerability, are often criticized. The criticism of ranking and comparing vulnerability across countries arises mainly because vulnerability is place- and context-specific, but also because of challenges owing to quality and availability of data, the selection and creation of appropriate indicators, underlying assumptions in weighting variables, and the interpretation of indices. Moreover, the dynamic nature of vulnerability would actually require a constant updating of such vulnerability scores (**Cutter, Boroff and Shirley, 2003; Eakin and Luers, 2006; Füssel, 2009; Klein, 2009; Hinkel, 2011**).

2.4.2 Vulnerability indicators in terms of exposure, sensitivity and adaptive capacity

The Intergovernmental Panel on Climate Change (IPCC) is considered to be the leading scientific international body for the assessment of climate change, and consequently the starting point for this paper is vulnerability as defined by the IPCC. According to the IPCC (2007) definition, vulnerability in the context of climate change is “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”. Thus, agricultural vulnerability to climate change can, for example, be described in terms of exposure to elevated temperatures, the sensitivity of crop yields to the elevated temperature and the ability of the farmers to adapt to the effects of this exposure and sensitivity by, for example, planting crop varieties that are more heat-resistant or switching to another type of crop.

The definition of the **IPCC (2007)** specifically highlights three components of vulnerability in the climate change context: exposure, sensitivity and adaptive capacity. It implies that a system is vulnerable if it is exposed and sensitive to the effects of climate change and at the same time has only limited capacity to adapt. On the contrary, a system is less vulnerable if it is less exposed, less sensitive or has a strong adaptive capacity (**Smit *et al.*, 1999; Smit and Wandel, 2006**).

In the climate change context, *exposure* relates to “the nature and degree to which a system is exposed to significant climatic variations” (**IPCC, 2001**). Exposure

represents the background climate conditions and stimuli against which a system operates, and any changes in those conditions. Thus, exposure as a component of vulnerability is not only the extent to which a system is subjected to significant climatic variations, but also the degree and duration of these variations (**Adger, 2006**). For vulnerability assessments the climatic variations can be aggregated as climate variability or specific changes in the climate system (e.g. temperature increases, variability and change in rainfall, etc.). It has to be noted that systems are often exposed to natural climate variability, independent of future climate changes; however, climate change can alter and increase the future exposure (**Lavell et al., 2012**). With regard to exposure it is also important to define the exposure unit, i.e. the activity, group, region or resource that is subjected to climate change (**IPCC, 2001**).

The *sensitivity* of a system to climate change reflects the “degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)” (**IPCC, 2007**). Sensitivity reflects the responsiveness of a system to climatic influences, and the degree to which changes in climate might affect it in its current form. Thus, a sensitive system is highly responsive to climate and can be significantly affected by small climate changes. Exposure and sensitivity together describe the potential impact that climate change can have on a system. However, it has to be noted that even though a system may be considered as being highly exposed and/or sensitive to climate change, it does not necessarily mean that it is vulnerable. This is because neither exposure nor sensitivity account for the capacity of a system to adapt to climate change (i.e. its adaptive capacity), whereas vulnerability is the net impact that remains after adaptation is taken into account (Figure 1). Thus, the adaptive capacity of a system affects its vulnerability to climate change by modulating exposure and sensitivity (**Yohe and Tol, 2002; Gallopin, 2006; Adger et al., 2007**).

The **IPCC (2007)** defines *adaptive capacity* as the ability (or potential) of a system to adjust successfully to climate change (including climate variability and extremes) to: (i) moderate potential damages; (ii) to take advantage of opportunities; and/or (iii) to cope with the consequences (**IPCC, 2007**). Adaptive capacity comprises adjustments in both behaviour and in resources and technologies (**Adger et al., 2007**). Recent literature emphasizes the importance of socio-economic factors for

the adaptive capacity of a system, especially highlighting the integral role of institutions, governance and management in determining the ability to adapt to climate change (Smit and Pilifosova, 2001; Brooks and Adger, 2005; Adger *et al.*, 2007; Engle, 2011; Williamson, Hesseln and Johnston, 2012). Accordingly, the adaptive capacity of a system can be fundamentally shaped by human actions and it influences both the biophysical and social elements of a system (IPCC, 2012). Research points out that some socio-economic determinants of adaptive capacity are generic (like, for example, education, income and health), whereas other determinants are specific to particular climate-change impacts such as floods or droughts (e.g. institutions, knowledge and technology) (Adger *et al.*, 2007). In general, the determinants are not independent of each other nor are they mutually exclusive as, for example, economic resources facilitate the implementation of new technologies and may ensure access to training opportunities. Lower levels of adaptive capacity in developing countries are very often associated with poverty (Handmer, Dovers and Downing, 1999; IPCC, 2012).

Adaptive capacity is generally accepted as a desirable property or positive attribute of a system for reducing vulnerability (Engle, 2011). The more adaptive capacity a system has, the greater is the likelihood that the system is able to adjust and thus is less vulnerable to climate change and variability. Vulnerability, its three components (exposure, sensitivity, adaptive capacity) as well as their determinants are specific to place and system and they can vary over time (i.e. they are dynamic), by type and by climatic stimuli (e.g. increasing temperature, droughts, etc.) (Smit and Wandel, 2006; Adger *et al.*, 2007). Thus, vulnerability is context-specific, and the factors that make a system vulnerable to the effects of climate change depend on the nature of the system and the type of effect in question (Brooks, Adger and Kelly, 2005), i.e. the factors that make farmers in semi-arid Africa vulnerable to drought will usually not be identical to those that make farmers in Northern Europe vulnerable to extreme weather events (cf. Schröter *et al.*, 2005a; Challinor *et al.*, 2007).

2.4.3 Alternative interpretations and concepts of vulnerability

Similar to the variety of vulnerability definitions, the literature provides a vast variety of interpretations and alternative concepts of vulnerability. The concepts often originate from different academic disciplines and professional fields of practice and they often differ with regard to their unit of analysis (e.g. individual, household or region) and methods (Adger, 2006; Füssel and Klein, 2006; O'Brien *et al.*, 2007;

Pearson and Langridge, 2008). The concept of climate change-related vulnerability has been comprehensively reviewed by many authors (see, for example, **Kelly and Adger, 2000; Alwang, Siegel and Jørgensen, 2001; Brooks, 2003, Adger, 2006; Füssel and Klein, 2006; Eakin and Luers, 2006; Eriksen and Kelly, 2007; O'Brien *et al.*, 2007**). Different concepts and interpretations of the character and cause of vulnerability produce different types of knowledge and therefore also result in different accentuations of strategies for reducing vulnerability (**Kelly and Adger, 2000; Füssel, 2007; O'Brien *et al.*, 2007; Maru, Langridge and Lin, 2011**). Moreover, the broad characteristics of alternative vulnerability interpretations can be quite confusing, and even more so in the climate change area, where researchers and stakeholders with different background knowledge collaborate. Therefore, it is not only beneficial but important to identify the thinking behind specific vulnerability analyses and to highlight the major differences in alternative vulnerability interpretations (**Eakin and Luers, 2006; Janssen and Ostrom, 2006**). Two of the most prominent vulnerability concepts in the context of climate change are outcome and contextual vulnerability, which differ mainly owing to their interpretation of vulnerability as being the end-point or the starting point of the analysis. Both concepts are graphically represented in Figure 2.1.

Outcome vulnerability (also known as the “*end-point*” interpretation) is a concept that considers vulnerability as the (potential) net impacts of climate change on a specific exposure unit (which can be biophysical or social) after feasible adaptations are taken into account. Thus, the outcome approach combines information on potential biophysical climate impacts with information on the socio-economic capacity to cope and adapt (**Kelly and Adger, 2000; Füssel, 2007; O'Brien *et al.*, 2007**).

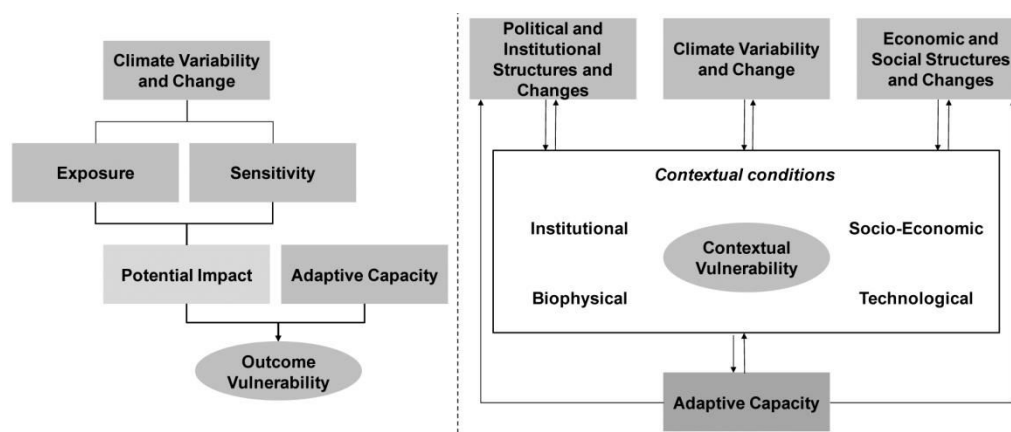


Figure 2.1: Outcome and contextual vulnerability

Source: Adjusted from Allen Consulting (2005) and O'Brian *et al.* (2007).

Based on natural science and *future* climate change model scenarios, outcome vulnerability approaches typically focus on biophysical changes in closed or at least well-defined systems. The boundaries between “nature” and “society” are quite firmly drawn and vulnerability is an outcome that can be quantified and measured. The outcome vulnerability is determined by the adaptive capacity of a system. However, regarding the adaptive capacity, most emphasis is given to biophysical components and the role of socio-economic components in modifying the effects of climate change is rather marginalized. Accordingly, the most vulnerable systems are considered to be those that will undergo the most dramatic physical changes. Studies that follow an outcome approach typically focus on technological solutions for adaptation and mitigation strategies to minimize particular impacts of climate change (Brooks, 2003; Eriksen and Kelly, 2007; Füssel, 2007; O'Brien *et al.*, 2007). Studies that focus on the vulnerability of agricultural yields to climate change in the future tend to follow an outcome vulnerability approach and typical technological solutions for adaptation in the agricultural sector include, for example, the use of different crop seeds, production techniques or water management (Tubiello and Rosenzweig, 2008; Challinor *et al.*, 2009; Peltonen-Sainio, 2012).

Contextual vulnerability (also known as the “*starting point*” interpretation) is a concept that considers vulnerability as the present inability of a system to cope with changing climate conditions, whereby vulnerability is seen to be influenced by changing biophysical conditions as well as dynamic social, economic, political,

institutional and technological structures and processes. Thus, in the contextual approach, vulnerability is seen as a characteristic of ecological and social systems that is determined by multiple factors and processes (**Adger, 2006; O'Brien *et al.*, 2007**).

Based on social science, contextual vulnerability approaches typically focus more on the *current* socio-economic determinants or drivers of vulnerability, i.e. social, economic and institutional conditions. Specific determinants that can increase or decrease a system's vulnerability include, for example, marginalization, inequity, food and resource entitlements, presence and strength of institutions, economics and politics (**Adger and Kelly, 1999; O'Brien and Leichenko, 2000; O'Brien *et al.*, 2004; Cardona *et al.*, 2012**). Thus the contextual interpretation of vulnerability explicitly recognizes that vulnerability to climate change is not only a result of biophysical events alone but is also influenced by the contextual socio-economic conditions in which climate change occurs. Nature and society are usually seen as joint aspects of the same context, i.e. a strong human-environment interrelation is assumed and the boundaries between nature and society are not firmly drawn.

The current vulnerability to climatic stimuli determines the adaptive capacity of a system, and climate change modifies not only the biophysical conditions but also the context in which climate change occurs. The contextual approach builds on the dual consideration of socio-economic and biophysical aspects that make a system vulnerable (**Turner *et al.*, 2003; O'Brien *et al.*, 2004; Polsky, Neff and Yarnall, 2007**). The general concept of socio-economic vulnerability is illustrated in **Schröter *et al.* (2005)** with an example on famine. **Schröter *et al.*, (2005)** argue that rather than focusing on the physical stress (e.g. drought) as the cause of famine, it might be more informative to focus on the social, economic and political marginalization of the individuals or groups as the cause for that famine. Likewise, the contextual approach emphasizes that the social and ecological context in which climate change occurs is likely to be as important as the climatic shock itself (**Bohle, Downing and Watts, 1994; Handmer, Dovers and Downing, 1999; Turner *et al.*, 2003; Ericksen, 2008**). This observation has been confirmed by quantitative research on agricultural production, such as quantitative work on the socio- economic factors that make grain harvests in China sensitive to rainfall anomalies (**Fraser *et al.*, 2008; Simelton *et al.*, 2009**). **Liverman (1990)** demonstrated that different crop yields during drought periods in Mexico could not be solely explained by different precipitation patterns but

were strongly influenced by different land tenure and the historical biases of farmers' access to productive resources. Likewise, **Vásquez-Léon, West and Finan (2003)** illustrated how differences in access to resources, state involvement, class and ethnicity result in significantly different vulnerabilities of farmers within a similar biophysical context. In an example for North America, **Mendelsohn (2007)** finds that about 39 percent of the variations in average crop failure rates across the United States of America can be explained by variations in soils and climate, which basically implies that other factors such as management skills, socio-economic, institutional and political conditions, account for the remaining 61 percent.

From the contextual interpretation, vulnerability can be reduced by modifying the contextual conditions in which climate change occurs so that individuals and groups are enabled to better adapt to changing climatic stimuli (**Adger, 2006; Eakin and Luers, 2006; Eriksen and Kelly, 2007; O'Brien *et al.*, 2007; Cardona *et al.*, 2012**). Accordingly, studies that follow a contextual approach typically focus on sustainable development strategies that increase the response and adaptive capacity of human populations to deal with climate change-related vulnerabilities (thereby addressing the need for adaptation policy and of broader social development). An important feature of contextual approaches is typically the involvement of the population and stakeholders of the system in identifying climate change stresses, impacts and adaptive strategies.

The alternative concepts and interpretations of vulnerability reflect the fact that vulnerability is context- and purpose-specific, and also specific to place and time as well as to the perspective of those assessing it (cf. **Adger, 2006; Füssel and Klein, 2006; O'Brien *et al.*, 2007; Pearson and Langridge, 2008; IPCC, 2012**). In practical terms, the question of “who is vulnerable to climate change?” can be addressed within both vulnerability approaches, with studies on outcome vulnerability focusing usually on vocations or professions, whereas contextual vulnerability focuses more on class, race, age or gender (**O'Brien *et al.*, 2007**). Outcome vulnerability approaches are also often associated with questions such as “what are the expected net impacts of climate change in different regions?” or “which sector is more vulnerable to climate change?” However, answering these questions may also form an important part of contextual approaches, especially if the economy of a society is dominated by activities that are sensitive to climate change (e.g. if the agricultural sector plays a

vital role in a society's economy). Thus, the question “why are some regions or social groups more vulnerable than others?” is closely related to contextual approaches (O'Brien *et al.*, 2007).

As vulnerability is context- and purpose-specific, none of the vulnerability concepts can be considered as being better or worse than the other. As highlighted in O'Brien *et al.* (2007), the outcome and contextual interpretations of vulnerability should be recognized as being two complementary approaches to the climate change issue. The two approaches assess vulnerability from different perspectives and they are both important to understand the relevance of climate change and respective responses (Kelly and Adger, 2000; Adger, 2006; O'Brien *et al.*, 2007). Moreover, in recognizing that any complex system commonly involves multiple variables (physical, environmental, social, cultural and economic), it seems imperative to assess the vulnerability of a system by using an integrated or multidimensional approach in order to capture and understand the complete picture of vulnerability in the context of climate change (Cardona *et al.*, 2012).

In summary, and as delineated above, climate vulnerability is characterized as a function of both biophysical and socio-economic vulnerabilities, with each defined by the three dimensions of exposure, sensitivity and adaptive capacity. When combined with specific likelihood of occurrence (either associated with biophysical changes or socio-economic variables), climate vulnerability becomes climate risk (Preston and Stafford-Smith, 2009). The relationship among different concepts associated with climate change vulnerability and risk are graphically depicted in Figure 2.2.

2.4.4 Characterization of current and future vulnerability

The discussion on alternative interpretations of vulnerability highlights that there are two different temporal references (time horizons) for assessing vulnerability. While the conceptualization of outcome vulnerability focuses on future vulnerability, contextual vulnerability focuses on current vulnerability. This distinction can mostly be attributed to the different disciplines that are involved in research on vulnerability and adaptation (Preston and Stafford-Smith, 2009; cf. section above). As described above, natural scientists usually focus on biophysical determinants of climate change and thus assess future vulnerability as the end-point of the analysis. On the other

hand, scientists focusing on socio-economic determinants tend to focus on current vulnerability as the starting-point of the analysis.

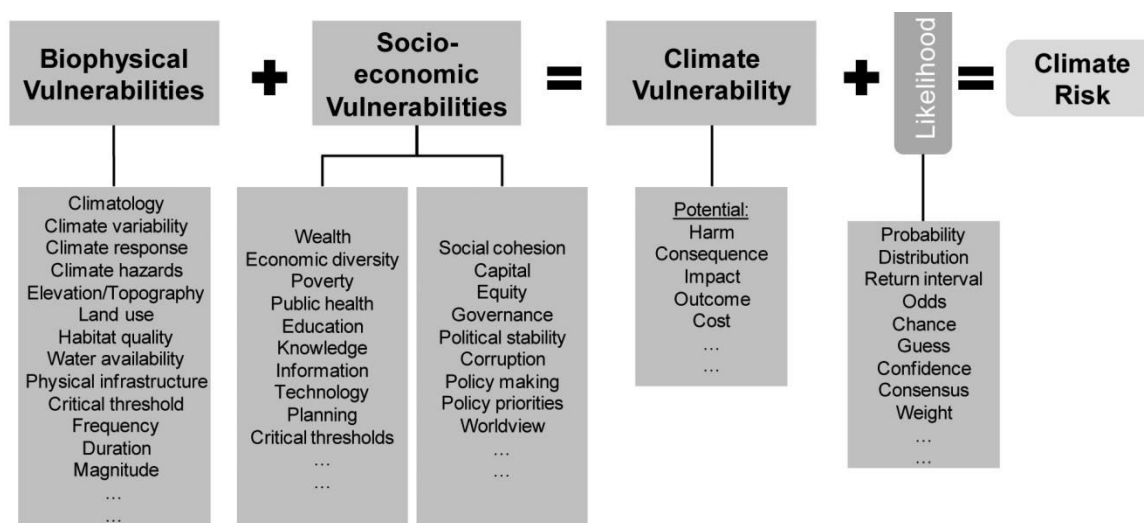


Figure 2.2: Relationship among different concepts associated with climate vulnerability and risk

Source: Modified from **Preston and Stafford-Smith (2009)**.

Preston and Stafford-Smith (2009) pointed out that both timeframes are important and valid and that it may be useful to maintain these different perspectives. However, nonclimatic (socio-economic) factors can strongly modify the climatic impacts of climate change (**Carter et al., 2007; Polsky, Neff and Yarnall, 2007**), which implies that future vulnerability also critically depends on present (autonomous and/or planned) adaptation processes (**Downing and Patwardhan, 2005; Carter et al., 2007, Carter and Mäkinen, 2011**). Consequently, to obtain a complete picture of vulnerability it seems necessary to combine both the two time horizons (current and future) and biophysical and socio-economic vulnerability determinants. **Preston and Stafford-Smith (2009)** depict the relationship between current and future vulnerability to climate change in a diagram, with both temporal references comprising biophysical as well as socio-economic determinants (Figure 2.3).

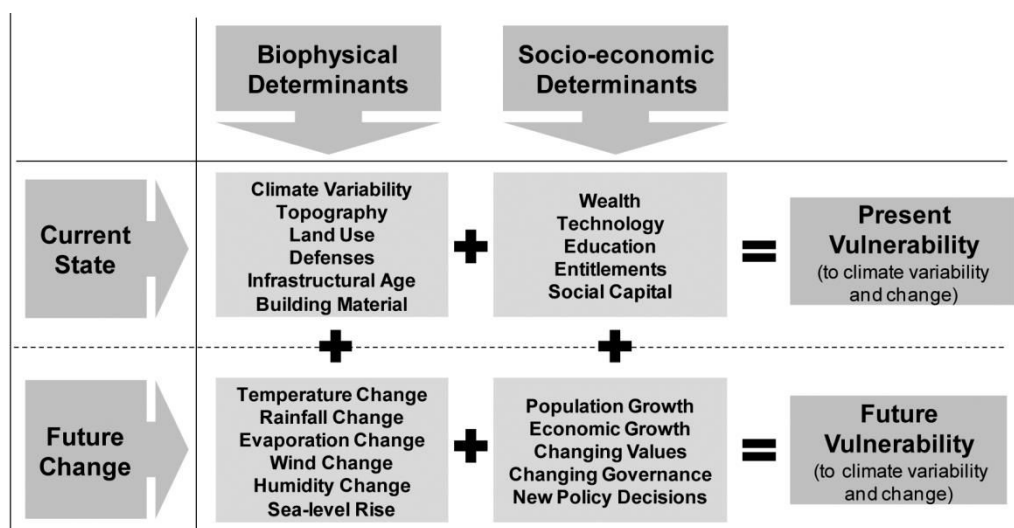


Figure 2.3: Relationships between current and future determinants of vulnerability to climate variability and change

Source: Slightly modified from **Preston and Stafford-Smith (2009)**.

2.5 Relationships between vulnerability and adaptive capacity

2.5.1 Adaptive capacity versus coping range

It is important to distinguish between adaptive capacity and coping range because both concepts are associated with different time-scales and represent different processes (**Smithers and Smit, 1997; Folke et al., 2002; Eriksen and Kelly, 2007**). A certain extent of variability is an inherent characteristic of climate, and most social and economic systems (including agriculture) are able to cope with some variations in climatic conditions – however mostly not with extremes of climate variability. The capacity of a system to accommodate deviations from “normal” climatic conditions describes the “coping range”, which can vary among systems and regions. Towards the edges of the coping range outcomes might become negative but are still tolerable, whereas beyond the coping range (i.e. beyond the vulnerability or critical threshold) the tolerance of the system is exceeded and it runs into a vulnerable state (**Smit and Pilifosova, 2001; Yohe and Tol, 2002; Jones and Mearns, 2005; Carter et al., 2007**; see Figure 2). For example, agricultural activities depend on local weather and climate conditions and can cope with some variability in these conditions, e.g. if it rains more or if it is drier over a given period of time (such as a specific month, season or year). However, if the conditions become too extreme (e.g. heavy rainfall,

floods or extended droughts) and exceed the coping range, then this may result in severe effects for productivity levels and diminish livelihoods.

Understanding the coping range and vulnerability thresholds of a system is a prerequisite for the assessment of likely climate change impacts and the potential role of adaptation. Coping range and adaptive capacity of a system are certainly related, but it is important to distinguish between the two concepts when attempting to measure the ability of a system to respond to adverse consequences of climate change (**Eriksen and Kelly, 2007**). The concept of the coping range is a practical conceptual model because: (i) it fits the mental models that most people have with regard to risk; and (ii) it helps to link the understanding of current adaptation to the climate and adaptation needs under climate change (**Jones and Boer, 2005; Jones and Mearns, 2005; Carter et al., 2007**). In contrast, adaptive capacity defines: (i) the preconditions (including social and physical elements) that are necessary to enable adaptation; and (ii) the ability to mobilize these elements (**Nelson et al., 2007**).

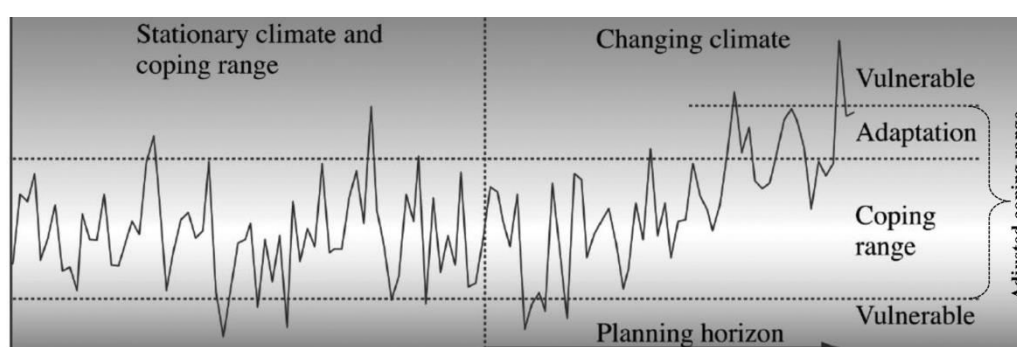


Figure 2.4: Relationships between climate change, coping range, vulnerability thresholds and adaptation

Source: Slightly modified from **Jones and Mearns (2005)** by adding the adjusted coping range.

Adaptive capacity represents the potential of a system to adapt rather than the actual adaptation (**Brooks, 2003**). In turn, adaptation represents the adaptation actually realized or aimed at to be realized in the future. This implies that through adaptation the coping range of a system can be expanded (or adjusted). Thus, the coping range as presented in the left part of Figure 3 represents the capability of a system to deal with current variations in climatic conditions. This coping range can be adjusted through adaptation, which in turn reduces the vulnerability of a system in the future (right part of Figure 2). Hence, the coping range represents one component of adaptive capacity

(with the adaptive capacity going beyond the actual coping range) and any adaptation can only take place within the adaptive capacity of a system.

Patwardhan (2006) examined that some explicit linkages between the objectives of vulnerability and adaptation assessment would be very helpful for identifying the nature of assessment required, and the data and information necessary. The study concluded with some thoughts regarding directions for research with regard to vulnerability and adaptation assessment.

Adger (2006) reviewed the research traditions of vulnerability to environmental change and the challenges for present vulnerability research in integrating with the domains of resilience and adaptation. Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt. Antecedent traditions include theories of vulnerability as entitlement failure and theories of hazard. Each of these areas has contributed to present formulations of vulnerability to environmental change as a characteristic of social-ecological systems linked to resilience. Research on vulnerability to the impacts of climate change spans all the antecedent and successor traditions. The challenges for vulnerability research are to develop robust and credible measures, to incorporate diverse methods that include perceptions of risk and vulnerability, and to incorporate governance research on the mechanisms that mediate vulnerability and promote adaptive action and resilience. These challenges are common to the domains of vulnerability, adaptation and resilience and form common ground for consistency and integration.

Adaptive capacity is defined in the glossary of the **IPCC (2001, p. 982)** TAR as “The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.” Because adaptation does not occur instantaneously, the relationship between adaptive capacity and vulnerability depends crucially on the timescales and hazards with which we are concerned. The vulnerability, or potential vulnerability, of a system to climate change that is associated with anticipated hazards in the medium- to long-term will depend on that system’s ability to adapt appropriately in anticipation of those hazards. However, vulnerability to hazards associated with climate variability that may occur in the immediate future will be related to a system’s existing short-term coping capacity rather than its ability to pursue long-term adaptation strategies. For a more detailed discussion of the

relationship between vulnerability and adaptive capacity within the context of different types of climate-related hazard the reader is referred to **Brooks (2003)**.

Smit and Wandel (2006) reviewed the concept of adaptation of human communities to global changes, especially climate change, in the context of adaptive capacity and vulnerability. It focuses on scholarship that contributes to practical implementation of adaptations at the community scale. In numerous social science fields, adaptations are considered as responses to risks associated with the interaction of environmental hazards and human vulnerability or adaptive capacity. In the climate change field, adaptation analyses have been undertaken for several distinct purposes. Impact assessments assume adaptations to estimate damages to longer term climate scenarios with and without adjustments. Evaluations of specified adaptation options aim to identify preferred measures. Vulnerability indices seek to provide relative vulnerability scores for countries, regions or communities. The main purpose of participatory vulnerability assessments is to identify adaptation strategies that are feasible and practical in communities. The distinctive features of adaptation analyses with this purpose are outlined, and common elements of this approach are described. Practical adaptation initiatives tend to focus on risks that are already problematic, climate is considered together with other environmental and social stresses, and adaptations are mostly integrated or mainstreamed into other resource management, disaster preparedness and sustainable development programs.

Adaptation in the context of human dimensions of global change usually refers to a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity. Numerous definitions of adaptation are found in climate change literature, mostly variations on a common theme. **Brooks (2003, p. 8)**, describes adaptation as “adjustments in a system’s behavior and characteristics that enhance its ability to cope with external stress”. **Smit et al. (2000, p. 225)**, in the climate change context, refer to adaptations as “adjustments in ecological-socio-economic systems in response to actual or expected climatic stimuli, their effects or impacts.” **Pielke (1998, p. 159)**, also in the climate context, defines adaptations as the “adjustments in individual groups and institutional behaviour in order to reduce society’s vulnerability to climate.” Based on their timing, adaptations can be anticipatory or reactive, and depending on their degree of

spontaneity they can be autonomous or planned (**Fankhauser et al., 1999; Smit et al., 2000**).

The concepts of adaptation, adaptive capacity, vulnerability, resilience, exposure and sensitivity are interrelated and have wide application to global change science. Analyses range in scale from the vulnerability and adaptation of an individual or household to a particular climate stress such as drought, through the vulnerability and adaptation of a community to multiple stresses, to the vulnerability of humankind (or the global ecosystem) to all stresses and forces. Applications also vary by the phenomena of interest (biological, economic, social, etc.), and by time scale (instantaneous, months, years, decades, centuries).

Given the diversity of decision contexts that can be informed by climate change vulnerability assessments and of normative preferences, the design of vulnerability indices is as much a political as a scientific task. The development of aggregated national-level vulnerability indices requires substantial normative choices in the selection and aggregation of diverse information across time, affected systems and regions, and impact metrics, which largely determine the resulting vulnerability ranking. All existing indices of vulnerability to climate change show substantial conceptual, methodological and empirical weaknesses including lack of focus, lack of a sound conceptual framework, methodological flaws, large sensitivity to alternative methods for data aggregation, limited data availability, and hiding of legitimate normative controversies. As a result, there is little agreement regarding the most vulnerable countries (**Füssel, H.M, 2009**).

2.6 Policy measures to counter climatic vulnerability

Patwardhan (2006) In most discussions of climate change, climate policy has commonly been used to refer to mitigation policy. While mitigation is certainly important, developing countries have no obligations for mitigation under the UN Framework Convention on Climate Change. For these countries, issues of vulnerability and adaptive capacity are perhaps more germane, and it is therefore important to examine adaptation policy as a key element of overall climate policy. It is here that we often run into the first road-block of differing jurisdictions. In many countries, and India is no exception, climate policy often lies within the jurisdiction of the Environment Ministry, as the issue is framed in terms of response to an environmental problem. On the other hand, adaptation is linked to core developmental

issues, whether with regard to infrastructure or institutions or sectors such as water resources, agriculture or health. These sectors are generally the responsibility of different agencies and ministries within the government. Therefore, perhaps one of the first steps to increase the visibility of climate policy would be to frame the issue of climate policy in terms of developmental priorities and policies.

The assessment of vulnerability in the context of extreme climate events and historical climate variability is another important avenue for engaging the policy community. A focus on climate variability automatically brings to the fore the way in which socio-economic systems becomes vulnerable to climate hazards. At the same time, this analysis provides insights that are relevant immediately, as we have to deal with extreme climate events well before the full range of consequences of mean changes in the climate state become apparent. Also, response to extreme climate events is often within the jurisdiction of state and local governments. As a result, this focus allows one to engage policy-makers that are typically not a part of the global climate policy process.

Finally, improved understanding of vulnerability and adaptive capacity is essential for identifying and realizing the full benefits of developmental projects, and in ensuring that such projects, particularly infrastructure projects, do not lead to maladaptation with regard to future climate change.

Vulnerability is often reflected in the condition of the economic system as well as the socioeconomic characteristics of the population living in that system. **Patnaik and Narayanan (2005)** constructed a picture of socioeconomic context of vulnerability by focusing on indicators that measure both the state of development of the region as well as its capacity to progress. Vulnerability of a particular district is measured by the frequency of occurrence of extreme events, in this case the occurrence of cyclones, storms and depressions. The study aims to build a vulnerability index and rank the various coastal districts of these highly vulnerable states in terms of their performance on the index then analysed the climate change policies that have to be integrated with sustainable development strategies. Specifically, the paper looks at four different sources of vulnerability: viz., the climatic factors, demographic factors, agricultural factors and occupational factors. Also a composite index has been created for the infrastructure development for the districts in question. The results from the index on vulnerability, infrastructure,

agricultural development and demographic patterns are compared to capture the true nature of vulnerability of the people living in these areas.

Many of the strategies and activities designed to achieve adaptation to climate change overlap with and will be integrated into those taken to achieve national development goals, poverty alleviation, disaster risk reduction and other dimensions of sustainable development and resilience (e.g., the green economy, green jobs and green growth). Simultaneously, efforts to mitigate climate change are gathering momentum and are generating changes within human society as well (**Klein et al. 2007**).

Mitigation efforts may profoundly transform societal systems with respect to energy, land use, infrastructure and manufacturing, with the potential for far-reaching consequences at local, national and global scales. Understanding the complex nature of VIA-mitigation interactions is a high priority in order to make possible more effective elaboration of development pathways that achieve desired combinations of adaptation and mitigation and that maximize co-benefits and minimize undesired side-effects (**Wilbanks, 2010; Wilbanks and Sathaye, 2007**).

The applicability of existing policy tools for addressing this interface should be explored and guidance developed for how decision makers can choose appropriate tools that integrate adaptation, mitigation and sustainable development and for the particular conditions they are addressing (**Yohe and Leichenko, 2010**). Research is needed to understand the complexities of the challenge and to determine which potential organizational and governance structures can be effective in different contexts (**Klein et al. 2007; Wilbanks and Sathaye, 2007**).

Planning and design are critical to regional vulnerability reduction and effective adaptation because they can have long-term effects and can change the way people behave (**Saavedra and Budd, 2009; Smit and Pilifosova, 2003; Tanner et al. 2009**). Innovative design can invoke and illuminate new visions of possible futures and inspire further creativity and optimism. There is a major role for both the arts and the humanities in such planning and design. Changes in engineering standards, coastal and flood zone planning and management, requirements for private and public sector climate hazard disclosure and in public and private insurance and reinsurance markets could also lead to a 'new normal' that catalyzes large-scale changes in mitigation, sustainable development and adaptation potential (**Dawson, 2007**).

Research is needed on the effectiveness of planning and design for climate change responses in urban areas, their surrounding infrastructure and resource-sheds and rural areas (**Tanner et al. 2009**). The role of innovative design in adaptation, mitigation and sustainability paradigms should be investigated as well. Key questions include how to minimize impacts of transition on the most vulnerable communities, the extent to which transitional costs (e.g., shoreline retreat) should be borne by those exposed to the hazard or society as a whole and how to ensure that all stakeholders are included in long-term decision-making (**Smit and Pilifosova, 2003**). Integrated research is needed across private and public entities on how insurance can provide incentives, data and projections in support of adaptation, mitigation and sustainable development. Research on how to minimize the risk of perverse incentives, including those that can be associated with price distortions in insurance markets, would also be beneficial.



METHODOLOGY

For any researcher to fulfil their stated objectives, a sound research methodology with appropriate tools of analysis is essential to draw a meaningful inference from the analysis of collected information and for the generalization of the findings. Hence, this chapter deals with the description of study area, data base, sampling procedure, analytical framework, models, and explanation of important concepts related to study. The novelty of this study is that it has considered climatic and socio-economic factors together to arrive at the vulnerability rating. The methodology of vulnerability assessment is based on the integration of various climatic and socio-economic factors following the multi-criteria decision-making technique in a geographical information system (GIS). The chapter is subdivided in to following sections:

3.1. Profile of the Bihar State

3.2. Data base and sampling design

3.3. Analytical tools and techniques employed

3.1. Profile of the Bihar State

The state Bihar is located in the eastern part of the country. It is bordered on the north by the Kingdom of Nepal, on the west by Uttar Pradesh, south by Jharkhand, and north – east by West Bengal. Bihar with a geographical area of 94,163 sq km (2.85 % of the country) lies between 21⁰ 58' to 27⁰ 31' North Latitude and 83⁰ 19' to 88⁰ 17' East longitude and has been divided into 9 divisions and 38 districts. Bihar can be broadly divided into two physiographic units, the Plains and the Plateau. The topography is mainly plain in the North, sloping towards the South has big rivers like Ganga, Sone, Poonpoo, Falgu, Karmanasa, Durgawati, Kosi, Ghaghara, etc. flowing through it.

Climate: The climate of the state on the whole pleasant and salubrious. The year may be classified in to four seasons. (i) Cold weather season from about the December to February (ii) Hot weather season from March to May (iii) Southwest monsoon from June to September and (iv) Retreating southwest monsoon from October to November.

The mean annual temperature of the State is 25⁰ C with mean annual maximum of 39⁰ C and mean annual minimum of 11⁰ C. The state enjoys a continental monsoon type of climate owing to its great distance from the sea. Hence its climate is tropical to sub tropical characterized by high temperature during summers, and mild during winter. The average annual rainfall varies from 1100 to 1250 mm. The state is divided into three agro – climatic zones:

Agro–Climatic Zone I

North Bihar Plains comprising of West Champaran, East Champaran, Gopalganj, Siwan, Saran, Sitamarhi, Muzaffarpur, Vaishali, Madhubani, Darbhanga, Samastipur districts of Bihar.

Agro–Climatic Zone II

North Eastern Plains comprising of Saharsa, Araria, Madhepura, Kishanganj, Purnia, Katihar, Supaul, Begusarai, Khagaria districts of Bihar.

Agro–Climatic Zone III

South Bihar Plains comprising of Bhojpur, Patna, Rohtas, Nalanda, Aurangabad, Gaya, Jehanabad, Nawada, Munger, Bhagalpur districts of Bihar.

Rainfall: The average rainfall in Bihar is 1053 mm. The rainfall in Bihar is largely due to the south-west monsoon, which accounts for around 85% of total rainfall in the state. The other sources (winter rain, hot-weather rain, and the north-west monsoon) account for the remaining 15%. The average normal rainfall in the state is more or less adequate for its agricultural operations. However, year-to-year changes lead to drought or flood, causing extensive damage to the crop production and the overall income of the state. Bihar has a geographical area of 9,360,000 hectares with three important agro-climatic zones: North-West, North-East, and South. The North-West zone has 13 districts and receives an annual rainfall of 1040–1450 mm. The North-East Zone has 8 districts; it receives rainfall ranging from 1200–1700 mm. the South Zone (17 districts) receives an average annual rainfall of 990–1300 mm.

Soil: The Soil of Bihar plane is thick alluvial in most part. The siwalik and older tertiary rocks. The soil is mainly loam, silt, clay and sand brought by the different

rivers flows through the state. This soil is deficient in phosphoric acid, nitrogen and humus, but potash and lime are usually present in sufficient quantity. There are three major types of soil found in Bihar which are as follows:

Piedmont Swamp Soil: - Found in North-Western part of West Champaran district.

Terai Soil: – Found in northern part of the state along the border of Nepal.

The Gangetic Alluvium: – The plain of Bihar is covered by gangetic alluvium (both new as well as old).

Topography: The topography of Bihar is an undulating giving rise to short-range variations in terrain and soil and water conditions. On the basis of topography, Bihar is divided into three main divisions, which are characterized by distinctive soil pattern, viz.:

- a) The upper terraces or uplands with light-textured soil.
- b) The middle terraces or medium lands with heavily textured soils.
- c) The lower terraces or lowlands with heavily textured soils.

The soil texture, an indelible part of the topography of Bihar, influences the soil moisture storage capacity, which along with the water-table depth, determines the availability of moisture for the cropping pattern.

Demography: Bihar is one of the India's poorest states and the most densely populated. The population of the state of Bihar has reached 10.41 crores in the census 2011 comprising of 52.14 per cent (5.43 crores) male and 47.86 per cent (4.32 crores) female population. The state has a population density of about 1106 people per sq. km. which is the highest among the different states of the country. The Census 2011 revealed that the state has the third highest population in the country and the growth rate is 25% which exceeds the national average of about 17%. The sex ratio is 918 number of female per thousand male.

Literacy rate: As per the Census, 2011, the overall literacy rate in the state is 61.80 per cent with male literacy rate is 71.20 per cent while female literacy rate is only 51.50 per cent.

Agriculture: Bihar lies in the river plains of the basin of the river Ganga. It is endowed with fertile alluvial soil with abundant water resources, especially ground

water resources. This makes the agriculture of Bihar rich and diverse. Rice, wheat, and maize are the major cereal crops. Arhar, urad, moong, gram, pea, lentils, and khesaria are some of the pulses cultivated in Bihar. Bihar is the largest producer of vegetables, which is dominated by potato, onion, eggplant, and cauliflower. In fruit cultivation, it is the largest producer of litchi and the third largest producer of pineapple, as well as a major producer of mango, banana, and guava. Sugar cane and jute are two other major cash crops of Bihar.

Cropping Pattern: The net sown area in Bihar is 60% of its geographical area. This percentage is much higher than the all-India average of 42%. Such a high percentage of cultivated land is possible for two reasons. First, most of Bihar is plain area suitable for agriculture. Second, most of the forest had been converted into farmland during the last 2000 years. Currently, land under forest constitutes only 6% of the area. Rice is cultivated in all districts of Bihar. Autumn rice, aghani rice, and summer rice are three different varieties of rice grown at three different times of the year. The average production of rice is around 5 million tonnes each year. The average annual wheat production is approximately 4-4.5 million tonnes. Maize is also cultivated, with an average annual production level of approximately 1.5 million tonnes.

Economy: The economy of Bihar is largely service-oriented, but it also has a significant agricultural base. The state also has a small industrial sector. As of 2012, agriculture accounts for 22%, industry 5% and service 73% of the economy of the state manufacturing has performed very poorly in the state between 2002 and 2007, with an average growth rate of 0.38% compared to India's 7.8%. Bihar has the lowest GDP per capita in India. Bihar state GDP is ranked 13 out of 28 Indian states.

3.2. Data base and sampling design

Study area: The climatic, agriculture and socio-economic vulnerability is calculated for the Kosi region of Bihar comprising of 8 districts namely, Saharsa, Araria, Madhepura, Kishanganj, Purnia, Katihar, Supaul and Khagaria.

Datasets: The study is based on fully secondary sources of data published by different government and private organization of national and international repute.

Data: The secondary data pertaining to various socio-economic and climatic indicators were collected and compiled from different sources, viz., Directorate of

Economics and statistics, Govt. of Bihar. The meteorological data were collected from the Indian Meteorology Departments (IMD) website and other published sources. The climatic data regarding monthly precipitation, maximum temperature, minimum temperature and diurnal temperature time series data constructed by Climatic Research Unit (CRU TS 3.0) at a spatial resolution of 0.5 x 0.5 degree for the time period 1976 – 2015 etc. were used to construct a climatic vulnerability index. The dataset was provided in the net CDF file format by BADC (<http://badc.nerc.ac.uk>) and India water portal met data from 1901 – 2002 this data was provided in the net CDF file format by http://www.indiawaterportal.org/met_data. Many a time district level data on annual rainfall, temperature etc. is not available. Therefore, the zonal average was used as proxy for analysis.

The agricultural data (production and productivity) of food grains were collected from SDDS-DES, Ministry of Agriculture, Govt. of India. The data pertaining to the number of livestock and occupational data were collected from Census of Bihar. Demographic data were collected from census of India for the period 1976-2015.

3.3. Analytical tools and techniques employed

3.3.1 The index approach to study vulnerability

The process of identification, quantification and prioritization of vulnerability in a system i.e. vulnerability assessment depends on the degree to which the people, environment or agriculture is affected by different climatic, agronomic and socio-economic factors. This may be conceptualized through construction of a composite vulnerability index. This index is based on several set of indicators that result in vulnerability of a region. It produces a single number, which can be used to compare different regions. Literature on index number construction specifies that there should be good internal correlation between these indicators. The relevance of this criterion depends on the relationship between the indicators and the construct they are supposed to measure. For this we must know whether the index is based on a ‘reflexive’ or a ‘formative’ measurement model. In the reflexive measurement model, the construct is thought to influence the indicators. For example, a poverty index is a good example of reflexive measurement because poverty influences the indicators such as literacy; expenditure and so on and all these indicators are correlated. On the other hand in the

formative model the indicators are assumed contribute to the construct. In the case of vulnerability index, all the indicators chosen by the researcher have impact on vulnerability of the region to climate change. For example, frequency of extreme events such as flood, drought earth-quakes, and length of coastline all contribute to vulnerability of the region to climate change. Hence vulnerability index is a formative measurement and the indicators chosen need not have internal correlation.

3.3.2 Construction of vulnerability index

Construction of vulnerability index consists of several steps. First is the selection of study area which consists of several regions. In each region a set of indicators are selected for each of the three component of vulnerability. The indicators can be selected based the availability of data, personal judgement or previous research. Since vulnerability is dynamic over time, it is important that all the indicators relate to the particular year chosen. If vulnerability has to be assessed over years then the data for each year for all the indicators in each region must be collected.

3.3.3 Arrangement of data

For each component of vulnerability, the collected data was arranged in the form of a rectangular matrix with rows representing regions and columns representing indicators. Let there be M regions/districts and let us say we have collected K indicators. Let X_{ij} be the value of the indicator j corresponding to i^{th} region then the table will have m rows and k columns.

Region/ District	Indicators					
	1			J		K
1	X_{11}	X_{12}		X_{1j}		X_{1k}
2						
i	X_{i1}	X_{i2}		X_{ij}		X_{ik}
m	X_{m1}	X_{m2}		X_{mj}		X_{mk}

3.3.4 Normalisation of indicators using functional relationship

Obviously the indicators will be in different units and scales. The methodology used in UNDP's Human Development Index (HDI) (UNDP, 2006) is followed to

normalize them. That is, in order to obtain figures which are free from the units and also to standardize their values, first they are normalized so that they all lie between 0 and 1. Before doing this, it is important to identify the functional relationship between the indicators and vulnerability. Two types of functional relationship are possible: vulnerability increases with increase (decrease) in the value of the indicator. Assume that higher the value of the indicator more is the vulnerability. For example, suppose we have collected information on change in maximum temperature or change in annual rainfall or diurnal variation in temperature. It is clear that higher the values of these indicators more will be the vulnerability of the region to climate change as variation in climate variables increase the vulnerability. In this case we say that the variables have $\uparrow$ functional relationship with vulnerability and the normalization is done using the formula

$$U_{ij} = \frac{X_{ij} - \text{Min } X_{ij}}{\text{Max } X_{ij} - \text{Min } X_{ij}} \dots\dots\dots (1)$$

Where,

X_{ij} is the value assigned by i^{th} respondent on j^{th} component

$\text{Min } X_j$ is minimum score on j^{th} component

$\text{Max } X_j$ is maximum score on j^{th} component

U_{ij} is unit value of i^{th} respondent on j^{th} component

It is clear that all these scores will lie between 0 and 1. The value 1 will correspond to that region with maximum value and 0 will correspond to the region with minimum value. On the other hand, consider adult literacy rate. A high value of this variable implies more literates in the region and so they will have more awareness to cope with climate change. So the vulnerability will be lower and adult literacy rate has $\downarrow$ functional relationship with vulnerability. For this case the normalized score is computed using the formula

$$U_{ij} = \frac{\text{Max } X_{ij} - X_{ij}}{\text{Max } X_{ij} - \text{Min } X_{ij}} \dots\dots\dots (2)$$

This method of normalization that takes into account the functional relationship between the variable and vulnerability is important in the construction of the indices. If the functional relation is ignored and if the variables are normalized simply by applying formula

(1), the resulting index will be misleading.

3.3.5 Methods of construction of vulnerability index

After computing the normalized scores the index is constructed by giving either equal weights to all indicators/components or unequal weights.

3.3.5.1 Simple average of the scores

When equal weights are given we use simple average of all the normalized scores to construct the vulnerability index by using the formula:

$$VI = \frac{\sum_j U_{ij}}{k}$$

Finally, the vulnerability indices are used to rank the different regions in terms of vulnerability. A region with highest index is said to be most vulnerable and it is given the rank 1, the region with next highest index is assigned rank 2 and so on.

3.3.5.2 Patnaik and Narain Method (Patnaik and Narayanan, 2005)

In this method, we first identify the possible sources of vulnerability and for each source several sub-indicators are identified. For example, we can group the variables into four different sources such as 1. Demographic, 2. Climatic, 3. Agricultural, and 4. Occupational. A list of possible sub-indicators in each group is

a) Demographic vulnerability: There are three components involved in this index to explain the demographic patterns of the people living in the respective region.

- i. Density of population (persons per square kilometre)
- ii. Literacy rate (percentage)
- iii. Infant mortality rate (deaths per '000 infants)

b) Climatic vulnerability: This index tries to take into account basic climatic variability. It combines six separate indices which are the variances of

- i. Annual rainfall (mm)
- ii. Maximum temperature ($^{\circ}\text{C}$)
- iii. Minimum temperature ($^{\circ}\text{C}$)
- iv. Diurnal temperature variation ($^{\circ}\text{C}$)

c) Agricultural vulnerability: This includes the following variables to predict the vulnerability related to agricultural activities.

- i. Production of food grains (tonnes / hectare)
- ii. Productivity of major crops (tonnes/ hectare)
- iii. Cropping intensity (percentage)
- iv. Irrigation intensity (percentage)
- v. Livestock population (Number per hectare of net sown area)
- vi. Forest area (percentage to geographic area)

d) Occupational vulnerability: Six indicators were taken to calculate the vulnerability related to occupational characteristics of people and all these variables are converted into per hectare of net sown area.

- i. Number of cultivators
- ii. Total main workers
- iii. Agricultural labourers
- iv. Marginal workers
- v. Industrial workers
- vi. Non workers

After normalization, the average index (AI) for each source of vulnerability is worked out and then the overall vulnerability index is computed by employing the following formula:

$$VI = \frac{\left[\sum_{i=1}^n (AI_i)^\alpha \right]^{\frac{1}{\alpha}}}{n}$$

Where, AI= Average index, n is the number of sources of vulnerability and $\alpha = n$.

The vulnerability indices can be worked out for each period of time and they can be compared to assess the changes in vulnerabilities over the period of time. After the values of the index are calculated for all the districts for each period of time and they were compared to assess the changes in vulnerabilities a ranking of the various districts can be carried out to identify the most vulnerable districts in terms of the indicators used for measurement. One advantage of this method is that we can compute the indices source-wise and ranks can be allotted source-wise also.

3.3.5.3 Methods with unequal weights

The method of simple averages gives equal importance for all the indicators which are not necessarily correct. Hence many authors prefer to give weights to the indicators. A survey of literature shows that the following methods are used to give weights:

3.3.5.3a Expert judgement method

In this method, the weights are assigned based on expert opinion. Obviously it is a subjective method. Each component is ranked in the descending order according to their relative importance and Garrett's ranking technique is involved to reveal the importance of each component based on their unit value after normalization. The experts in this field are asked to rank these four components according to vulnerability. The percentage positions thus obtained are transformed into scores on a scale of 100 points by using Garrett's table. From the scores so obtained, the average score was derived. This is termed as scale value (S_j) of each component. The unit values (U_{ij}) for each combinations and category of experts were multiplied by respective component scale value, summed up and divided by total scale value to get vulnerability Index (VI) of each of the combinations in different categories of experts. The value of SI is in percentage. Higher the VI higher will be the vulnerability of the that district.

$$VI = \frac{\sum_{i=1}^n U_{ij} * S_j}{\sum_{i=1}^n S_j}$$

Garrett's ranking technique

In this method, respondents are asked to rank the specific problems faced by them according to their own perception. The assigned rank is converted into percentage position which is subsequently transferred into Garrett score using Garrett's table. For each constraint, scores of individual respondents are added together and then divided by total number of respondents. Thus, mean score for each constraint has been ranked by arranging them in descending order.

$$\text{Percentage position} = \frac{100(R_{ij} - 0.50)}{N_j}$$

where,

R = Rank given for the i item by the j individual and

N = Number of items ranked by the j individual.

3.3.5.3 b Iyengar and Sudarshan's method

Iyengar and Sudarshan (1982) developed a method to work out a composite index from multivariate data and it was used to rank the districts in terms of their economic performance. This method is statistically sound and well suited for the development of composite index of vulnerability to climate change. Iyengar and Sudarshan's method proved to be superior to both the method of simple averages and the Patnaik and Narayanan's method as it gave weights to the indicators of vulnerability which were assumed to vary inversely with their variance over the regions. On the contrary, the main drawback in the other two methods was that they give equal importance for all indicators which may not necessarily be correct. A brief description of the methodology is given below.

It is assumed that there are M regions /districts, K indicators of vulnerability and X_{ij} , $i = 1, 2, \dots, M$; $j = 1, 2, \dots, K$ are the normalized scores. The level or stage of development of i^{th} zone, is assumed to be linear sum of X_{ij} .

$$\bar{y}_i = \sum_{j=1}^K w_j X_{ij}$$

Where, w 's ($0 < w < 1$ and $\sum_{j=1}^K w_j = 1$) are the weights. In this method the weights are

assumed to vary inversely, as the variance over the regions in the respective indicators of vulnerability. That is, the weight w_i is determined by

$$w_i = \frac{k}{\sqrt{\text{var}(y_i)}}$$

Where, k is a normalizing constant such that

$$k = \left[\sum_{i=1}^n \frac{1}{\sqrt{\text{Var}(y_i)}} \right]^{-1}$$

The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and distort inter regional comparisons. The vulnerability index so computed lies between 0 and 1, with 1 indicating maximum vulnerability and 0 indicating no vulnerability at all.

Thus after constructing the vulnerability index by method of unequal methods, the different districts of Kosi region were categorized according to high, moderate and low in following way:

1. **Highly vulnerable:** $> (\text{Standard Deviation} + \text{Mean})$
2. **Lowly vulnerable:** $< (\text{Standard Deviation} - \text{Mean})$
3. **Moderately vulnerable:** Between $(\text{Standard Deviation} \pm \text{Mean})$

Standard Deviation: The standard deviation is the most important measure of dispersion. It is found by taking the difference of each item in the series from arithmetic mean ($\bar{X}$) squaring this difference: summing all square difference's dividing by number of item and then extracting the square root or in a formula.

$$\text{S.D.} = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

Where,

x = An observation

$\bar{x}$ = Arithmetic mean of the population

n = Number of given observation

$x - \bar{x}$ = Deviation from the mean



PROFILE OF THE STUDY AREA

The profile area of the present study is spread over eight districts of the Kosi region of Bihar. Districts namely Supaul, Saharsa, Madhepura, Araria, Purnia, Katihar, Khagaria and Kishanganj are located in North region of Bihar. Salient features of the agro-economic as well as socio-economic situation pertaining to selected districts have been presented in this chapter.

The Latitude of Kosi River is 26.4517 and The Longitude of Kosi River is 86.8511. This River is known as the "Sorrow of Bihar" as the annual floods affect about 21,000 km² (8,100 sq mi) of fertile agricultural lands thereby disturbing the rural economy. Seven Rivers. The three major tributaries meet at Triveni, from where they are called Sapta Kosi meaning Seven Rivers. Kosi zone is one of the fourteen zones of Nepal. The headquarters of Kosi Zone is in Biratnagar. The Kosi river fan located in the northern part of India (in north-east Bihar) is one of the largest alluvial cones built by any river in the world. It is 180 km long and 150 km wide. The river basin is surrounded by ridges which separate it from the Yarlung Tsangpo River in the north, the Gandaki in the west and the Mahananda in the east. The river is joined by major tributaries in the Mahabharat Range approximately 48 km (30 mi) north of the Indo-Nepal border. Below the Siwaliks, the river has built up a megafan some 15,000 km². Kosi region comes under zone II and include 8 districts (Supaul, Saharsa, Madhepura, Araria, Purnia, Katihar, Khagaria, Kishanganj)

Soil

The region in general possesses alluvial soil. The soils are of poorly drained type. They are mostly moderately acidic to neutral. The areas close to the Kosi channels possess soil types of sandy loam, loamy sand and sand character, whereas, the areas away from the river channels consist of silty sand to sandy silt in nature. Deficiencies of zinc and boron and toxicity of manganese have been recognized in these areas.

Climate

The Kosi region of Bihar is located within the subtropical to warm temperate climates characterized by cool and dry winters and warm and wet summers (Timsina

and Connor 2001). In the Kosi region, paddy is usually grown during the wet summer season called kharif (May-June to October-November) and wheat during the dry winter season called rabi (November-December to March-April). The natural precipitation varies from 990 to 1700 mm. Most of the precipitation is received during the month of July to September. Soil pH varies from 6.5 to 8.4. Average temperature is between 35 to 40 degree Celsius throughout the summer. April and June are the hottest months of the year, while December to January is winter season in Bihar because of its location in Northern hemisphere. Winters in Bihar are mild with average temperature ranging between 5 to 10⁰ Celsius. Bihar receives maximum rainfall during South-West monsoon season which prevails from June to September.

Agriculture and industry

Agriculture in the state is prone to natural calamity. Whereas the North Bihar districts are affected by the recurrent flood the south Bihar districts are prone to lack of rainfall. The coverage under rice, wheat, total maize and oilseeds crop is estimated to increase about 9.6, 6.7, 2.0 and less than 1 per cent respectively in 2012-13 from 2014-2015, while the area under total pulses decrease to about 10 per cent.

SUPAUL

Location:- Supaul district is located in North region of Bihar bordering Nepal and its lie between 25°37'-26°25' N latitude and 86°22'-87°10' E longitude.

Topography: Supaul district is a part of Kosi division. The district is bounded by Nepal in the north, Saharsa in the south, by Araria district in the East and on the west by Madhubani district. This district covers an area of 2,420 sq km.

Climate and rainfall: The climate of Supaul district is highly induced by Himalayan terrain. Rains are very frequent here. The average temperature stands for 30°C. the atmospheric pressure comes down up to 980-990. The monsoon arrives up to normally in mid June decreasing temperature up to almost 10°C and increasing moisture content in the air to 80-90%. the average rainfall range is 1400-1600mm.

Soil: The soil of this district is alluvial and sandy with a varying nature of acidic and basic. Though it is deficient in mineral such as sodium, Potassium and Magnesium.

The pH factor of soil varies from 5.5 to 8.5. This district of the soil is suitable for paddy, wheat, pulses, sugarcane, vegetables and jute.

Demography: Supaul is densely populated district with 719 people residing in every sq Km, whereas this is 880 for the entire state of Bihar. Population of this district is 1,05,558. Out of the population living in the urban areas 55,788 are males and 49,770 are females. Actual number in the total population of 17, 32,578; male population is 9,02,207 and female population is 8, 30,371. In percentage terms it is 52.1% and 47.9% respectively. Sex ratio of this district is male with total 920 female per 1000 male. Literacy rate of Supaul district as per census 2011 is **72.74 %** of which males and females are **80.78 %** and **63.64 %** respectively. Actual number of literate people are 63,939 in urban region in which males and females are 37,684 and 26,255 respectively.

Land use Pattern: Agriculture is the main occupation of the people in Supaul district. Total area of this district is 677 km². In general, there are four agricultural seasons in one year; (i) *Bhadai* (ii) *Aghani* (iii) *Rabi* & (iv) *Garma*. During Rabi the important crops, which are grown in the district include wheat, rice, corn, mustard, jawar etc. Paddy is mainly grown during June to November. The climate allows round the year vegetable cultivation of cabbage, cauliflower, carrot, radish, chilli, capsicum, beans and long beans, gourd, potato, onion, coriander, turmeric, ginger, Garlic etc. The staple cereal of this district is rice. The net sown area in the district is at 1328 km² with the average agriculture intensity at 151%.

SAHARSA

Location & Geographical Area : The area of Saharsa district is 1,645 km². Saharsa district is situated at the south-eastern parts of the megafan. The Kosi River flows at the western boundary of the district. It is located at 25°53'N 86°36'E 25.88°N 86.6°E.

Topography: It has an average elevation of 41 metres (134 feet). Saharsa and its surrounding areas are a flat alluvial plain forming part of the Kosi river basin. This makes the land very fertile. However, frequent changes in the course of the Kosi, one of the largest tributaries of the Ganges, have led to soil erosion.

Climate and rainfall: Climate of this district is warm and humid with high temperature and medium to high rainfall. The average minimum temperature is 80°C to

100C and maximum is 240C to 250C. The normal rainfall of district stands at 1360 mm with the monsoon (June- September) component of 1138 mm (84%). The late September-October rains (locally known as 'Hathia') are very crucial to agriculture in the region and their timing and distribution make all the difference between plenty and scarcity.

Soil: In general, soil of this district is alluvial. The soils are of poorly drained type. The areas close to the Kosi channel so soil types of sandy loam, loamy sand and sand character, whereas, the areas away from the river channels consist of silty sand to sandy silt in nature. The soils in general are fine textured away from the river course and rivulets and coarse textured along their courses.

Demography: According to the 2011 census, the population of Saharsa district was 1,900,661 in which (female: 997,174 and male: 903,487). Population density of the district is 1,127 people per sq. km. The area of the district is 1,645 km². Sex ratio is at 910 per 1000 male. Average literacy rate of Saharsa were 53.20%. Gender wise literacy rate of male and female is 63.56 and 41.68 respectively.

Agriculture: Agriculture is the major occupation of this district and paddy is the main crop. Saharsa is famous for its varieties of Mango's and Summer Berry known as Litchi. Makhana, cultivated in the flood plains of Kosi River forms one of the most important cash crops.

MADHEPURA

Location & Geographical Area: Madhepura district is situated in the Plains of Kosi River and located in the North-eastern part of Bihar at longitude between 25°. 34 to 26°.07' and latitude between 86°.19' to 87°.07' it occupies an area of 1,788 km². Madhepura district is surrounded by Araria and Supaul district in the north, Khagaria and Bhagalpur district in the south, Purnia district in the east and Saharsa district in the West.

Climate and rainfall: The climatic condition of the area is generally humid and tropical. maximum temperature of this district 35 to 40 degree Celsius and the minimum temperature varies from 7 to 9 degree Celsius. The normal rainfall is 1231 mm. The rainfall during the SW monsoon i.e. months commencing from June to September, usually amounts to 80.85% of the total rainfall.

Soil: The soil of this district is Younger Alluvium deposited by Kosi River. The area, generally inundated by flood of Kosi, possesses the soil of sandy loam to sandy deposits. Elsewhere, the soil is of heavier texture. The soils association types-Recent alluvium, non-calcareous, non-saline is overlying the entire area, mostly high to medium textured, acidic to neutral and generally yellowish to white to light grey in colour.

Demography: In 2011, Madhepura had population of 2,001,762 (Census 2011) of which male and female were 1,047,559 and 954,203 respectively. density of Madhepura district for 2011 is 1,120 people per sq. km. In 2011 census, child sex ratio is 930 girls per 1000 boys compared to figure of 927 girls per 1000 boys of 2001 census data. Out of the total Madhepura population for 2011 census, 4.42% lives in urban regions (Fig 2) of district. In total 88,461 people lives in urban areas, whereas, 95.58 % population, i.e. 1,913,301, of the districts lives in rural areas of villages. male and female literacy rate of this district is 61.77 and 41.74 respectively

Agriculture: There are four cropping seasons prevalent in the study area namely, 1) Garma (March-June), 2) Bhadai (April/May – August/Sept.), 3) Aghani (June-November), and 4) Rabi December- March). Bhadai and Aghani seasons are clubbed for all practical purposes as Kharif season. The staple cereal of this district is rice.

ARARIA

Location & Geographical Area: Araria is located in the extreme eastern part of Bihar along the border of Nepal. It lies between 25° 56' North and 26° 35' North latitudes and between 87° 03' East and 87° 42' East longitude in the extreme eastern part of the *Kosi* plain. The district is surrounded in the north by Nepal; in the east by the Bahadurganj block of Kishanganj district; in the south by Purnea district and in the west by Supaul.

Climate and rainfall: Araria is distinctly feels the dry and hot seasons. However, the months of December and January register decrease in both the maximum and minimum temperature. The month of December records 28.1 ° C and 5.7 ° C as mean monthly maximum and minimum temperatures respectively. January is the coldest month in the district which records 26.9 ° C mean monthly maximum and 4.1 ° C mean monthly minimum temperature respectively. The temperature continuously increases

till May. The mean monthly temperature in May is 29.5 ° C. heavy rainfall begins with an average of 32.5 cm in June and 44.25 cm in July, while in August and September the amount of rainfall is recorded on an average 39.5 cm and 32.25 cm respectively.

Soil: The Araria district is covered by non-calcareous, non-saline soil of recent alluvium formation, brought down by the streams of Kosi system. soils of the whole plain are of one major type of alluvial. the basis of clay and sand proportion the soil may be categorized into five general types of clay soil: clay-loam soil, loamy soil, sandy loam soil and sandy soil. It is most suitable for rice cultivation. While the clay loam soil is suitable for the cultivation of wheat, gram, maize and oilseeds.

Demography: Araria is one of the densely populated districts. In 2011 Araria had total population of 2124831 persons and an area of 2830 sq. km. The average density of population for the district is 750 persons per square kilometre. Decadal population growth is 44.77 per cent. Literacy rate of the district is 44.15 for male and 25.18 for female. The sex-ratio of Araria district reported 921 females per 1000 males

Agriculture: There are three agricultural seasons in the district viz., *Rabi*, *Kharif* and *Zaid*. *Rabi season* starts in October or November and harvesting is done in March and April. The important *rabi* crops are wheat, barley, gram, peas, mustard, linseed, potato etc. *Kharif season* starts in July and the harvesting is done in October or November. The millets, maize, arhar, rice and sugarcane etc. are the main crops of *Kharif season*. *Zaid crops*, which are of relatively little importance, occupy the fields from April to July. The average cropping intensity of Araria district is 142.93.

PURNIA

Location & Geographical Area: Purnia district is situated in Northern part of Bihar. It is surrounded by Araria & Kishanganj district in north, Katihar district in south, west Bengal in east and Saharsa & Madhepura district in west. Its geographical area is 3229 Sq Km.

Topography: Purnia has an area of 3229 sq km. it is a level, depressed tract of country, It is traversed by several rivers flowing from the Himalayas, which afford great advantages of irrigation and water-carriage. Its major rivers are the Kosi, the Mahananda, the Suwara Kali and the Koli. In the west the soil is thickly covered with

sand deposited by changes in the course of the Kosi. Among other rivers are the Mahananda and the Panar.

Climate and rainfall: The area has warm and humid climate with high temperature and medium to high rainfall. The average minimum of 30°C to 100°C and maximum of 240°C to 250°C. The normal rainfall for the district stands at 1470.4 mm.

Soil: The soil of the area is consisting for the most part of rich, loamy soil of alluvial formation. Younger Alluvium deposited by Kosi River. The area, generally inundated by flood of Kosi, possesses the soil of sandy loam to sandy deposits.

Demography: According to 2011 census the district of Purnia had total population of 2024621 persons and an area of 2830 sq. km. Purnia district is one of the densely populated districts. The average density of population for the district is 850 persons per square kilometre. The decadal population growth for the district is 40.77 per cent. Literacy rate of the district is 41.09 for male and 23.19 for female. The sex-ratio of Purnia district reported 855 females per 1000 males.

Agriculture: Agriculture is the major occupation of Purnia district and paddy is the main crop.

KATIHAR

Location & Geographical Area: Katihar district is situated in the plains of North Eastern part of Bihar State, surrounded by Purnea district (Bihar) in the north and the west, Bhagalpur district (Bihar) and Sahebganj district (Jharkhand) in the south and Malda district and Uttar Dinajpur district (Paschim Bengal) in the east. Latitude 25° 42' – 26° 22' N and Longitude 87° 10' – 88° 05' E

Topography: The topography of the Katihar district has been very much affected by the floods of river Ganges, Mahananda and Koshi.

Climate and rainfall: The soil is mainly young loam rejuvenated every year by constant deposition of silt, clay and sand brought by different streams. This soil is deficient in phosphoric acid, nitrogen and humus, but potash and lime are usually present in sufficient quantity.

Soil: The district has alluvial soil and due to deposit of sand-silt by rivers and soil in southern and the western part has become sandy. The land is slightly higher in the

North and gradually slopping towards the south. The slope is gradual. There is no hill in the district except a small block in Manihari Block which is composed of nodular lime stone.

Demography: In 2011 the district of Katihar had total population of 3068149 persons and an area of 30570 sq. km. The district of Katihar is one of the densely populated districts. The average density of population for the district is 850 persons per square kilometre. Literacy rate of the district is 40.99 for male and 35.37 for female. The sex-ratio of Purnia district reported 846 females per 1000 males.

Agriculture: Paddy is the main agricultural crops. Jute and paper Mills is the main industry. Mahananda and Ganga are the main river.

KHAGARIA

Location & Geographical Area: Khagaria is located at 25°15' -25°44'N &86°17'14'' - 86°52'5'' E. initially it was a part of Munger & is surrounded by Bhagalpur and Madhepura in the east, Begusarai and Samastipur in the west, Saharsa in the north and in the south it is Munger and Begusarai. The geographical area of the district khagaria is 1485.8 sq. km. with north to south-23 km and east to west-48 km .

Topography: The district occupies the area of 1485.8sq.km and is surrounded by seven rivers namely Ganges, Kamlabalan, Koshi, BudhiGandak, Karch, KaliKoshi and Bagmati. These rivers cause flood every year which causes great loss of life and prosperity including livestock. The land has an average elevation of 36 metre(118ft).

Climate and rainfall: The average rainfall in the district is 1056 mm. maximum and minimum temperature of the district is 37.38 and 20.17 respectively.

Soil: The district has alluvial soil and due to deposit of sand-silt by rivers and soil in southern and the western part has become sandy. The land is slightly higher in the North and gradually slopping towards the south.

Demography: According to 2011 census the district of Khagaria had total population of 3360549 persons and an area of 30570 sq. km. The Katihar district is one of the densely populated districts. The average density of population for the district is 950 persons per square kilometre. Literacy rate of the district is 48.81 for male and 32.16 for female. The sex-ratio of Purnia district reported 850 females per 1000 males.

Agriculture: Major crop of this district is Maize, paddy, wheat oilseed and vegetables are grown on commercial basis.

KISHANGANJ

Location & Geographical Area: Kishanganj district occupies an area of 1,884 square kilometres (727 sq mi), comparatively equivalent to Maui in the United States. Kishanganj district is surrounded by Araria district in the west, Purnia district in the south-west, Uttar Dinajpur district of West Bengal on the east, and Darjeeling district of West Bengal and Nepal on the north. Kishanganj district is located between 25° 20' and 26° 30' north latitudes, and 87° 7' and 88° 19' east longitudes.

Topography: The district occupies the area of 1485.8sq.km and is surrounded by Major rivers flowing through the district are Mahananda, Kankai, Mechi, Donk, Ratua and RamzanSudhani.

Climate and rainfall: The climate of the district on the whole pleasant and salubrious .The average rainfall in the district is 2175 mm. maximum and minimum temperature is 37.38 and 20.17 respectively.

Soil: Soil of the district Kishanganj is light, sandy loam to loam and its physical range is 5.8 to 8.0(mostly natural soil but some are slightly acidic and some saline). The nutrient status in soil is low to medium with deficiency of zinc and phosphorous pentoxide.

Demography: The population of Kishanganj district was 12.94 lakhs Majority of the population (70.7 per cent) was of minority communities. Sex ratio was 940 female per thousand male and literacy rate was 31.02 per cent (lower than the state and national average). The literacy rate of this district was 49.13 per cent for male and 37.98 per cent for female.

Agriculture: The primary occupation is agriculture. major crop of this district is Maize,paddy,wheat oilseed and vegetables are grown on commercial basis.



EXPERIMENTAL FINDINGS AND DISCUSSION

An investigation on “**A study on Vulnerability to agriculture in Kosi region of Bihar**” was carried out. The observation recorded on different aspects are presented in this chapter in tabular and are illustrated in the form of figures, whatever found necessary. The different methods have been analysed to construct the vulnerability index.

The findings of the present study have been presented in the following sub section.

5.1 Identification of indicators

5.2 Functional relationship of indicators

5.3 Construction of vulnerability index

5.4 Policy measures

5.1.1 Identification of indicators

Quantitative assessment of vulnerability is a subjective method. The first and foremost important aspect for assessment of vulnerability was to identify the factors responsible for the climate change. The factors were identified on the basis of previous studies carried out to so far to assess the vulnerability and also for construction of human development index (UNDP, 2006). The identified socio-economic factors were grouped into demographic, climatic, agricultural and occupational factors or an indicator which was found to be significant sources of vulnerability. Data pertaining to demographic factors have been presented in Table: **5.1.1a**

It was observed from the Table-5.1.1a that under demographic factors, data on population density, literacy rate as well as infant mortality of selected district under study revealed that density of population (Persons/km²) i.e. 23.90/square kilo-meter was found maximum in Kishanganj district followed by Araria 23.67 and was found minimum in Khagaria (18.98) district, however data pertaining to Literacy rate (%)

was concerned it was found maximum in Khagaria (53.72) followed by Supaul (48.11) and minimum literate peoples were found in Katihar district (41.81).

Table 5.1.1 a. Demographic features of the districts of Kosi Region of Bihar

District	Population Density (persons per sq. km)	Literacy Rate (%)	Infant Mortality Rate (death/'000infants)
Supaul	22.69	48.11	4.17
Saharsa	19.17	46.91	4.47
Madhepura	19.40	44.19	4.88
Araria	23.67	46.02	4.73
Purnea	22.40	43.36	4.30
Katihar	21.74	41.81	4.40
Kishanganj	23.90	44.60	4.80
Khagaria	18.98	53.72	4.90

Source: Census of India,2011

Regarding infant mortality rate i.e. death/'000 it was found maximum in Khagaria district (4.90) followed by Madhepura (4.88) and least infant mortality rate was observed in Supaul district which was 4.7 Persons/km². It may further revealed from the table that remaining district under study like Purnia, Araria, and Saharsa literacy rate and infant mortality was also found most significant factor which affects the vulnerability.

On the basis of above findings, it may be conclude that those districts having high population density, lower literacy rate along with high mortality rate was more sensitive towards the vulnerability. However, those districts having low infant mortality, high literacy rate with low population density were found to be more capable to withstand with the situation. It is mainly due to fact that some socio economic factors compel more towards vulnerability in some identified districts than that of others.

Table 5.1.1b Climatic features of Kosi region of Bihar

District	Rainfall (mm)	Max temp.(°c)	Min. temp. (°c)	Diurnal temp. (°c)
Supaul	1470	30.55	16.06	11.40
Saharsa	1370	27.06	17.35	11.41
Madhepua	1239	35.54	18.81	11.75
Araria	1822	33.4	16.01	13.08
Purnia	1407	35.93	16.8	12.84
Katihar	1233	36.38	16.23	12.99
Kishangaj	2265	39.21	13.7	12.36
Khagaria	1345	36.38	20.17	11.35

Source: Water portal

The other factors identified were the climatic variables. Under the climatic factors, data on rainfall, temperature as well as diurnal variance was ascribed for assessment of vulnerability. It was due to fact that Kosi region of Bihar was badly affected from extreme i.e. from flood and drought. It was observed from the table that Kishanganj district was supposed to be badly affected from rainfall i.e. 2265mm and maximum temperature (39.21 °c) followed by Khagaria and least affected district was Katihar (1233mm). It is because of the fact that unseasonal and prolonged rains cause damage to the crops whether in the field and also to the harvested produce kept at the threshing floor.

Third identified factors were the production & productivity of cereal crop, cropping intensity, & livestock population of the districts under study.

Table 5.1.1c Agricultural features of the district of Kosi region of Bihar

It was observed from the trend analysis that agriculture sources was found to be most important factor which affects the vulnerability. It was due to fact that 83 percent of famers of Bihar are marginal farmers. They do not have enough capacity to withstand with situation or not capable to bear the risk associated with the agricultural i.e. production risk, market risk and some other unforeseen events. Data pertaining to average production of food grains (tonnes) was concerned.

It was found maximum in Saharsa (154053) followed by Katihar (147094), Supaul (133525) and was minimum in Khagaria district (102190). However, productivity of food grains (tonnes/ha) was maximum in Katihar (1.47) followed by Saharsa (1.30), Supaul (1.24), Purnea (1.22), Araria (1.21), Kishanganj (1.09), Khagaria (1.08) and was minimum in Madhepura (1.03). It may further revealed that to cope with situation, adoption of subsidiary enterprises is important. It may be seen that livestock population (no./ha of net sown area) was found maximum in Araria district (3.71) followed by Purnea (3.67), Supaul (3.25), Madhepura (2.97), Saharsa (2.51), Kishanganj (2.09) and was minimum in Khagaria district i.e. 1.68, respectively. It was observed that all the mentioned indicators had shown inverse relationship between vulnerability as declined in the production and productivity affects the income level of the farmers however cattle population in some district like Araria, Katihar and Purnea.

The fourth identified factor ascribed for vulnerability was occupational factor. Under this, we took the data on no of cultivator/ net sown area, total worker, agricultural labourer, Industrial worker and other worker per ha of net sown area which have been presented in Table **5.1.1d**.

Result revealed that occupational vulnerability of district under study was found to be second most important factors for the study. As vulnerability is closely associated with this factors because agriculture is most affected factors leads to people migrated for other occupation where agricultural factors was badly affected from heavy rainfall change in maximum and minimum temperature etc. From the date logically, the district of Purnia had maximum number of Agricultural labour followed by Araria (536). It means as far vulnerability was concerned this factors was negatively related with vulnerability. However, in the district of Kishanganj (201) no. of cultivators was less. It means that district had more problems with occupational factors.

On the basis of above finding, it may be conclude that agricultural factors was assumed to be most important factors followed by occupational factors and climatic factors. Other factors responsible for vulnerability to the district were demographic.

5.2 Functional relationship of indicators

The list of selected indicators is shown in **Table 5.2** vulnerability indices suggested many important hypotheses relating the vulnerability of the districts to climate change with various key socio-economic, climatic agricultural and occupational indicators.

The density of population of the district was found to influence its demographic vulnerability and consequently the overall vulnerability to climate change. It was hypothesised to be positively related to the vulnerability to climate change *i.e.*, with the increase in the number of persons per sq. km., the vulnerability to climate change would increase due to its direct impact on global warming. This would be due to increased pollution and Green House Gas (GHG) emissions as a result of greater use of vehicles, enormous industrial carbon emissions, rapid use of non-renewable and other natural resources, greater use of non-biodegradable materials like polythene, growing human settlements and their activities leading to faster destruction of natural systems, deforestation, habitat destruction, extinctions, more exploitation of other living forms and non-living systems like rivers. For the people, there would be increase in illness and diseases, shortage of natural resources such as water, land, food, shortage of infrastructure such as medical facilities/medications etc. Moreover, any occurrence of extreme events viz., droughts, floods etc. is likely to be more catastrophic for the people living in these districts (Patnaik and Narayanan, 2005).

The literacy rate, on the other hand, was hypothesised to have a negative functional relationship with demographic vulnerability and thereby, on the overall vulnerability to climate change. Literacy rate indicates the adaptability of the population to both adverse impacts caused by shocks and the opportunities created. It also implies the proportion of expenditure on education in total public expenditure which indicates investment in human capital. It was seen that a high value of this variable implied more literates in the region and so greater awareness to cope up with climate change impacts (Palanisami *et al.*, 2009).

Climatic vulnerability was assumed to be positively related to the indicators such as variances in annual rainfall as well as minimum and maximum temperature variances. This indicated that any increase in the variability of these climatic indicators would increase the vulnerability of the districts to climate change. Glantz and Wigley (1986) studied the worldwide climate change and showed that any change

in climatic variables like temperature and precipitation could induce vulnerability of food production in a major way. For instance, the climatic abnormality during the 1970s caused relatively small fluctuations in the world cereal supplies.

Yield is more uncertain with unfamiliar technology. Quite often the objective risks are uncertain due to weather fluctuations, susceptibility to pests, uncertainty regarding timely availability of crucial inputs etc. However, it could be seen that higher yields of crops led to higher incomes of the farmers and thereby increasing their risk bearing ability to various shocks. An increase in the livestock population per gross cropped area also results in an increase in the farmer's incomes through various animal husbandry based activities, thereby its negative functional relationship towards vulnerability. Similarly, the percentage of total food crops and non-food crops, the cropping and irrigation intensities and the net sown area in the district, each of these comprising the agricultural indicators were also hypothesised to have a negative influence on the vulnerability to climate change.

Lastly, all the occupational indicators were hypothesised to have a negative functional relationship to climate change as greater employment meant more secure incomes which would in turn increase the risk bearing capacities of the people.

5.3. Comparision of different districts in relation to vulnerability index

Quantitative assessment of vulnerability is usually done by constructing 'vulnerability index'. To construct and compare the vulnerability indices the mentioned period was subdivided into 4 parts i.e. from 1976-1985, 1986-1995, 1996-2005 and 2006-2015. It means spatial as well as temporal vulnerability was also quantified.

For the construction of vulnerability index we used simple average score method, Patnaik and Narayanan Method by giving equal weight towards the variable. However, Iyengar and Sudarsan's method and Expert judgement method was also used to construct the vulnerability indices. Next two methods was mainly based on giving unequal weight towards the indicators. It is because some parameters influenced more to the vulnerability and vice-versa.

It was observed from the **Table 5.3.1** that for the first period Kishanganj district was found most vulnerable district (0.71) followed by Khagaria (0.62), Saharsa (0.5), Purnia (0.48), Katihar (0.46), Madhepura (0.46) and Supaul(0.42).

However Araria was found to be least vulnerable district as vulnerability index was (0.34).

However during 2nd period i.e. from 1986-1995 observed that Kishanganj district was most vulnerable (0.71) followed by Khagaria (0.64) Purnea (0.49), Saharsa(0.49), Supaul(0.49), Araria (0.45), Katihar(0.4) and Mahepura(0.37) was found to be least vulnerable district.

In period 3rd i.e from 1996-2005, the Kishanganj district remained stand first as for as vulnerability to climate is concerned. However Khagaria (3.13) followed by Purnea (2.24), Saharsa (2.13), Supaul (2.12), Madhepura (1.93) and Araria(1.75) ranked 2nd, 3rd, 4th, 5th, 6th and 7th respectively. It may further revealed from the table that Katihar (1.74) was found to be least vulnerable district in comparison to all other districts under study.

During sub-period i.e. from 2006-2015 indicated that Kishanganj again stand first ranked towards the vulnerability followed by Khagaria (1.21), Saharsa (0.94), Madhepura (0.75), Katihar(0.71), Purnea (0.67) and Araria (0.61) and was found to be least vulnerable was Supaul (0.37).

It may further observed from the table that district wise overall vulnerability i.e. from 1976-2015, the most vulnerable was Kishanganj (0.69) however the least vulnerable district was Araria (0.32). Other district like Khagaria (0.66), Supaul (0.55), Purnea (0.51), Saharsa(0.46), Madhepura (0.45), Katihar (0.33) stand 2nd, 3rd, 4th, 5th, 6th and 7th position when vulnerability towards climate change is concerned.

It may be conclude that Kishanganj district had lower adaptive capacity and most sensitive towards danger which has already been shown in functional analysis that, in Kishanganj district the annual rainfall change in maximum and minimum temperature which is component of danger found to be maximum and as far as literacy rate and occupational vulnerability was concerned. It was found to less no. of average cultivator/ha. Net sown area over the period in comparison to other district. However in Araria despite having less adaptive capacity i.e. literacy rate, average productivity. It was found to be least vulnerable it is due to fact that occupation sources of vulnerability in Araria was less in comparison to other district. The climate and agriculture is clearly associated with vulnerability (**Hiremath et.al**, 2012) the climatic factor like change in rainfall, maximum and minimum temperature was also found to be least vulnerable under simple score method.

Component wise/sources wise vulnerability index of mentioned district under study has been presented in Table 5.3.2

The district Kishanganj was found to be most vulnerable (0.81) district followed by Khagaria (0.80), Supaul (0.67), Purnea (0.57), Madhepura (0.56), Saharsa (0.56), Araria (0.37) respectively as 1st to 7th. However, least vulnerable over the same period was Katihar.

Period wise analysis i.e. temporal vulnerability of different district under study indicated that district Kishanganj was remained stand 1st ranked in all sub-period i.e. from 1976-1985, 1986-1995, 1996-2005 respectively. However, in period 3rd and 4th Supaul was found to be next vulnerable district followed by Purnea and Saharsa. However, Araria (p-1) and Madhepura was found to be least vulnerable during 2nd, 3rd and 4th period under study.

The district whose vulnerability index was change occur the period was Supaul, during 1st period it was estimated as 2nd least vulnerable district in between to 1976 to 2006-2015 its position was changed and was estimated to be placed in position 2nd as for as vulnerability to climate change concerned.

On the basis of above finding it may be conclude that Kishanganj was most vulnerable district and district Katihar found to be least vulnerable. When we compare it with different period Khagaria was found to be next to Kishanganj followed by Supaul, Purnea, Madhepura, Saharsa and Araria. It is because climate, agriculture, demographic as well as occupational sources of vulnerability.

In above mentioned district has influenced more as far as adaptive capacity of districts under study is concerned. Cropping intensity and average productivity has shown declining trend over the mentioned period however occupational features is also responsible to recover from the stresses. Some of districts during sub-period shown more vulnerable and improve occur the sub-period eg. Saharsa

Source wise contribution of vulnerability index presented in the **Table 5.3.2**

It was observed from the table that out of eight districts selected in the year 2015, the district of Kishanganj ranked 1st and the district of Araria ranked last in overall vulnerability to climate change. This implies that district Kishanganj was most vulnerable and district of Araria was the least vulnerable during that period.

The agriculture sector played a significant role in ranking Kishanganj district at the first position by contributing to the tune 46.12 % to the overall vulnerability followed by occupational (34.16%), climatic (13.46%) and demographic (6.26%).

It may further be observed that Khagaria (12.47) followed by Saharsa (10.03), Purnea (9.65), Madhepura (9.28), Katihar (9.14) and Supaul (8.41) ranked 2nd, 3rd, 4th, 5th, 6th and 7th respectively with respect to overall vulnerability to climate change consequently being categorized as above vulnerable district of the Kosi region of Bihar. The value of vulnerability index varied from 0.36 (Katihar) to 0.81 (Kishanganj) during the period (1976-1985).

In period 2nd i.e. 1986-1995 the Kishanganj (14.3) remain ranked first in the overall vulnerability to climate change amongst all the selected districts of Kosi region of Bihar followed by Khagaria (12.74), Purnea (9.75), Saharsa (9.7), Supaul (9.1), Araria (8.01), Katihar (7.42) and Madhepura (7.34) was found to be least vulnerable district replaced by Araia if we compared it with 1st period (i.e. from 1976-1985).

It may be conclude that due to major contribution of agricultural and occupational indicators these districts was placed most vulnerable and least vulnerable districts because agriculture as well as occupational factors are again played a predominant role for the ranking of the vulnerability as first and last respectively.

During period 3rd i.e. from 1996-2005 the district of Khagaria (29.78) ranked first in the overall vulnerability to climate change amongst all the selected district of the Kosi region replacing Kishanganj (14.92) district. The 2nd position followed by Supaul (9.19), Purnea (8.87), Araria (8.18), Saharsa (7.91), Madhepura (7.45) and Katihar (5.52) respectively.

Thus it may be conclude that district Khagaria was classified as highly vulnerable and Katihar was least vulnerable.

In the year 2006 to 2015, Kishanganj (14.14) district retained its first position with agricultural and occupational indicators towards the overall vulnerability to climate change. It may be conclude that due to major contribution of agricultural and occupational indicators these districts was placed most vulnerable and least vulnerable districts because agriculture as well as occupational factors are again played a predominant role for the ranking of the vulnerability as first and last respectively It may further observed that Khagaria, Purnea, Saharsa, Supaul, Madhepura, Katihar were ranked 2nd, 3rd, 4th, 5th, 6th and 7th respectively with respect to overall vulnerability. Hence the left district was Araria ranked as least vulnerable district with respect to climatic indicators accounting for 6.70%.

It may be conclude that Madhepura district ranked last in 3 mentioned period however in 1976-2015, Katihar was the least vulnerable and in period. Period I Araria was the least vulnerable district so far as contribution towards different sources of vulnerability concerned.

However, the district of Katihar was ranked last means least vulnerable district with respect to overall vulnerability to climate change over the period. It clearly indicating that for such a positive scenario can be described to be higher productivity of cereal crop. High cropping intensity along with greater livestock population in the district. The agricultural university played a greater role in the transfer of technology to the farmer's door for enhancing crop productivity. Similarly, wastage of water may be ascertain the agricultural scenario of the district.

Across all the period 8 (1976-2015) all the period the district Supaul was the most vulnerable index with respect to occupational vulnerability (42.64).

It was observed from the table that with giving unequal weight to all the component of vulnerability i.e. exposes, sensitivity and adaptive capacity in almost all period, the district of Kishanganj was found most vulnerable and Katihar was found to be least vulnerable except for the period 1976-1985, it was replaced by Araria.

It may further observed that data pertaining to average maximum rainfall of district under study in the mentioned period was 28575.64mm and minimum rainfall was 13642.83mm in Kosi region of Bihar. District wise analysis indicated that the Kishanganj district whose annual rainfall was estimated to be 28575.64mm which was maximum for the region followed by Araria, Supaul, Purnea and Katihar. However, the district of Khagaria shown minimum rainfall amongst all selected district under study.

However, the variance of maximum and minimum temperature was observed to be highest in the district Kishanganj followed by Khagaria, Saharsa, Supaul, Madhepura, Purnea, Katihar and was found to be least variation in the district of Araria. It implies that in these districts whose variance of annual rainfall, maximum and minimum temperature as well as diurnal variance was found to be minimum could be ascribed as least vulnerable district and vice-versa.

Data pertaining to sensitivity component was concerned, i.e. population density of district, infant mortality rate, drought and flood, it may be observed that due to reoccurrence of flood leads to damage to the crop or livestock population was found maximum in Kishanganj (21.954) district followed by Araria (21.896) and

Purnea (20.882). It implies that Kishanganj was remain stand in first position with respect to sensitivity component of vulnerability was concerned.

It may be concluded that distribution of population was highly skewed in favour of the poor in the Kosi region of Bihar. Further, one can also see that the extreme events i.e. flood and drought was very high in these districts. Therefore, the people in these regions must have suitable disaster management to hedge against the greater vulnerability that they face. Being vulnerable overall period, it is important to develop adaptive capacity for the people.

Data pertaining to adaptive capacity shown that the district of Kishanganj followed by Khagaria, Supaul was ranked 1st, 2nd and 3rd ranked. However, the district Araria was found to be least vulnerable with respect to overall vulnerability was concerned.

Expert judgement method

Through expert judgement methods, degree of vulnerability in the study region from 1976-2015 for the the degree of vulnerability index was calculated separately for each period i.e. 1976-1985,1986-1995,1996-2005,2006-2015 selected districts under study has been presented in the table.

In period (1976-1985) on the basis of three subsequent test **Table 5.3.4a** as based on exposure Araria was highly vulnerable district followed by Saharsa, Supaul, Purnia, Kishanganj, Khagaria, Madhepura and least vulnerable district was Katihar. Due to sensitivity it shows the Saharsa was the most vulnerable which vulnerability index was (76.30) and least vulnerable district was Kishanganj followed by Araria, Madhepura, Khagaria, Supaul,Purnia and Katihar. Due to adaptive capacity Kishanganj was highly vulnerable district (89.4) followed by Khagaria, Supaul, Saharsa, Madhepura, Purnia ,katihar and Araria was the least vulnerable district.

It was observed that on the basis of exposure which includes variance of annual rainfall, change in maximum temperature and minimum temperature as well as diurnal variance, the district of Araria was found to be highly vulnerable district. The degree of vulnerability for the same ≥ 47.96 .

The district of Supaul followed by Saharsa, Madhepura, Purnea, Khagaria and Kishanganj were placed under moderate vulnerability. Its range of vulnerability varied from 23.15-47.96 and amongst least vulnerable district, the Araria was found to be

least as its range was ≤ 23.15 . However, from the sensitivity component out of eight district, Saharsa was highly vulnerable district (≥ 67.57).

The district of Supaul, Madhepura, Araria, Purnea, Katihar and Khagaria were placed under moderate vulnerable district (30.71-67.57). However, the district of Araria was again placed under least vulnerable district with respect to sensitivity component of vulnerability to climate change was concerned.

3rd and foremost important component of vulnerability was adaptive capacity. As findings itself indicated that degree vulnerability on the basis of adaptive capacity was concerned, it was estimate to be the district of Kishanganj and Khagaria were placed under highly vulnerable district. However, the district of Supaul, Saharsa, Madhepura, Purnea and Katihar were placed under moderate vulnerability whose degree of vulnerability varied from 25.40-74.13 and the district of Araria was considered as least vulnerable district amongst all the selected district under study so far. Its range of vulnerability was varied from ≤ 25.40 .

In the Period (1986-1995) **Table 5.3.4 C** data revealed that due to exposure the Araria district which was highly vulnerable (60.28) followed by Saharsa, Supaul, Purnia, Khagaria, Kishanganj, Madhepura and least vulnerable district was Katihar(14.92). Due to sensitivity Purnia was the most vulnerable which vulnerability index was (74.55) and least vulnerable district was Supaul, followed by Katihar, Khagaria, Kishanganj, Saharsa, Araria, and Madhepura. Due to adaptive capacity, Kishanganj was highly vulnerable district (86.35) followed by Khagaria, Supaul, Purnia, Madhepura, Saharsa, Araria and Katihar was the least vulnerable district.

It was observed that on the basis of exposure which includes variance of annual rainfall, change in maximum temperature and minimum temperature as well as diurnal variance, the district of Araria was found to be highly vulnerable district. The degree of vulnerability for the same ≥ 52.89 .

The district of Saharsa, Supaul, Purnea, Khagaria followed by Kishanganj, Madhepura, and were placed under moderate vulnerability. Its range of vulnerability varied from 26.17-52.89 and amongst least vulnerable district, the Katihar was found to be least as its range was ≤ 26.17 . However, from the sensitivity component out of eight district Purnea was highly vulnerable district (≥ 69.54).

The district of Saharsa, Madhepura, Araria, Purnea, Katihar and Khagaria were placed under moderate vulnerable district (35.71-69.54). However, the district of Supaul was least vulnerable district with respect to sensitivity component of vulnerability to climate change was concerned.

3rd and foremost important component of vulnerability was adaptive capacity. As findings itself indicated that degree vulnerability on the basis of adaptive capacity was concerned, it was estimate to be the district of Kishanganj and Khagaria were placed under highly vulnerable district. However, the district of Supaul, Saharsa, Madhepura, Purnea and Katihar were placed under moderate vulnerability whose degree of vulnerability varied from 28.3-73.5 and the district of Araria was considered as least vulnerable district amongst all the selected district under study so far. Its range of vulnerability was varied from ≤ 28.3 .

In period iv (1996-2005), table no. **5.3.4d** clearly shows that the component wise highly vulnerable district due to exposure Kishanganj (53.33) which got maximum score and followed by Araria, Purnea, Supaul, Saharsa, Khagaria, Madhepura and Katihar was the least vulnerable district. due to sensitivity Purnia was the most (71.53) and Supaul was the least vulnerable district(28.6) rest of six were the medium group and because of adaptive capacity Kishanganj was the most vulnerable district (86.39) followed by Khagaria, Supaul, Madhepura, Saharsa, Purnea, Araria and Katihar was the least vulnerable (22.28) district.

The district of Saharsa, Supaul, Purnea, Khagaria followed by Araria, Madhepura and were placed under moderate vulnerability. Its range of vulnerability varied from 26.82-47.74 and amongst least vulnerable district, the Katihar was found to be least as its range was ≤ 26.82 However, from the sensitivity component out of eight district, Purnea ,Katihar was highly vulnerable district(≥ 66.28).

The district of Saharsa, Madhepura, Araria, Kishanganj, Katihar and Khagaria were placed under moderate vulnerable district (36.79-66.28).However, the district of Supaul,was least vulnerable district with respect to sensitivity component of vulnerability to climate change was concerned.

3rd and foremost important component of vulnerability was adaptive capacity. As findings itself indicated that degree vulnerability on the basis of adaptive capacity was concerned, it was estimate to be the district of Kishanganj were placed under highly vulnerable district. However, the district of Supaul, Saharsa, Madhepura,

Purnea and Khagaria were placed under moderate vulnerability whose degree of vulnerability varied from 28.32-73.58 and the district of Araria was considered as least vulnerable district amongst all the selected district under study so far. Its range of vulnerability was varied from ≤ 28.32 .

In period iv (2006-2015), table no. **5.3.4f** clearly shows that the component wise highly vulnerable district due to exposure Purnea (62.72) which got maximum score and followed by Kishanganj, Supaul, Saharsa, Araria, Khagaria, Madhepura and Katihar is the least vulnerable district. due to sensitivity Purnia was the most (71) and Supaul was the least vulnerable district (26.93) rest of six were the medium group because of adaptive capacity most vulnerable district was Kishanganj (86.21) followed by Khagaria, Supaul, Madhepura, Saharsa, Purnia, Araria and Katihar was the least vulnerable (22.28) district.

It was observed that on the basis of exposure which includes variance of annual rainfall, change in maximum temperature and minimum temperature as well as diurnal variance, the district of Kishanganj was found to be highly vulnerable district. The degree of vulnerability for the same ≥ 54.88 .

The district of Saharsa, Supaul, Purnea, Khagaria followed by Araria, Madhepura and were placed under moderate vulnerability. Its range of vulnerability varied from 25.86-54.88 and amongst least vulnerable district, the Katihar was found to be least as its range was ≤ 25.86 . However, from the sensitivity component out of eight district, Purnea was highly vulnerable district (≥ 66.28).

The district of Saharsa, Madhepura, Araria, Kishanganj, Katihar and Khagaria were placed under moderate vulnerable district (36.33-66.26). However, the district of Supaul was least vulnerable district with respect to sensitivity component of vulnerability to climate change was concerned.

3rd and foremost important component of vulnerability was adaptive capacity. As findings itself indicated that degree vulnerability on the basis of adaptive capacity was concerned, it was estimate to be the district of Kishanganj were placed under highly vulnerable district. However, the district of Supaul, Saharsa, Madhepura, Purnea and Khagaria were placed under moderate vulnerability whose degree of vulnerability varied from 28.58-73.36 and the district of Araria was considered as least vulnerable district amongst all the selected district under study so far. Its range of vulnerability was varied from ≤ 28.58 .

In the Period (1976-2015) found table no. **5.3.4h** component wise highly vulnerable overall as best on exposure Purnia (61.01) district followed by Supaul, Madhepura, Khagaria, Katihar, Kishanganj, Saharsa and the least vulnerable district was Araria (36.23) due to sensitivity Kishanganj was the most (62.45) and Supaul was the least vulnerable district (17.5) because of adaptive capacity Kishanganj was most vulnerable district (85.57) followed by Khagaria, Supaul, Madhepura, Saharsa, Purnia, Araria and the least vulnerable district was Katihar (22.3).

It was observed that on the basis of exposure which includes variance of annual rainfall, change in maximum temperature and minimum temperature as well as diurnal variance, the district of Purnea was found to be highly vulnerable district. The degree of vulnerability for the same (≥ 55.64).

The district of Saharsa, Supaul, Khagaria, Katihar, Madhepura, and Kishanganj were placed under moderate vulnerability. Its range of vulnerability varied from 36.79-55.64 and amongst least vulnerable district, the Araria was found to be least as its range was ≤ 36.79 . However, from the sensitivity component out of eight district, Purnea was highly vulnerable district (≥ 66.28).

The district of Saharsa, Madhepura, Araria, Kishanganj, Katihar and Khagaria were placed under moderate vulnerable district (25.76-60.05). However, the district of Supaul, was least vulnerable district with respect to sensitivity component of vulnerability to climate change was concerned.

3rd and foremost important component of vulnerability was adaptive capacity. As findings itself indicated that degree vulnerability on the basis of adaptive capacity was concerned, it was estimate to be the district of Kishanganj were placed under highly vulnerable district. However, the district of Supaul, Saharsa, Madhepura, Purnea and Khagaria were placed under moderate vulnerability whose degree of vulnerability varied from 28.42-73.14 and the district of Araria was considered as least vulnerable district amongst all the selected district under study so far. Its range of vulnerability was varied from ≤ 28.58 .

Suggestions and policy implications

It is true that the fundamental issues like alleviation of poverty and fulfilling the basic conditions for human development are of primary concern but the importance of climate change cannot be neglected. What is required is a development strategy that encompasses both these concerns. Therefore climate change policies have to be integrated with sustainable development strategy such as social control,

pollution control, as well as emphasis towards regional crop planning *etc.* Some of the important suggestions and policy options may be:

1. In research priority setting, besides the criteria of poverty, equity, export competitiveness and sustainability, one more objective criteria of climate change should also be given due weightage. This would take care of sustainability aspect too.
2. Since the worst sufferers of climate change impacts are the rural communities, (who depends mainly on agriculture as their livelihoods), it is important to focus on the impacts of climate change on livelihoods, and re-establish the links among poverty, livelihood and environment. However, focusing on the communities only are not enough, and so long as the community initiatives do not become part of the government policies, it is difficult to sustain the efforts. Thus, the link between local, state and national governments to the community is of utmost importance.
3. A unique way of vulnerability reduction is through enhancing the capacities of local people and communities. Livelihood security should be the first and the foremost priority where the improvement of lifestyle is desired through income generation in different options: agriculture, aquaculture, fishing, animal husbandry. In the regions, which are highly vulnerable, policy makers should enact measures to support effective management of environmental resources, adaptation policies should increase the resilience of farming and food systems to climate change impacts while maintaining or increasing food production. For example- new cropping practices, timing of planting, better use of short-term and seasonal climate forecasting to reduce production risks.
4. Predicted impacts should be introduced into development planning in the future, including land use planning and necessary remedial measures should be included to reduce vulnerability in disaster reduction strategies.
5. Climate change prediction capability should be enhanced through link to the hydro-meteorological organizations.
6. Since vulnerability of agricultural sector towards climate change is high. Several adaptation options need to be considered. Sustainable land and water management combined with innovative agricultural technologies could mitigate climate change and help poor farmers adapt to its impacts. New adaptation and mitigation strategies must

urgently be applied to national and regional development programmes. As occupational vulnerability in some of the district like Supaul was very high, without these measures developing districts will suffer most and leads to increased in food insecurity.

7. In order to enhance the resilience of the agricultural sector, new strategies must be built around 'green' agricultural technologies, such as adaptive plant breeding, pest forecasting, rainwater harvesting and fertilizer micro dosing etc.
8. Further, an improvement in the agronomic practices of different crops such as revising planting dates, plant densities and crop sequences can help to cope with the delayed rainy seasons, longer dry spells and earlier plant maturity. Also, technologies for minimizing soil disturbance such as reduced tillage, conservation agriculture and crop rotation must be adopted. So far as the livestock sector is concerned, measures relating to utilization of fodder banks, control of livestock population and improvement in the livestock productivity, organizing of cattle camps and conservation of fodder must be undertaken. The dependence on agriculture should to be reduced, by encouraging other non-farm sources of income.
9. The policy makers must focus on generating better employment opportunities including income diversification options like focus on subsidiary enterprises for people in the regions where the incidences of out-migration are high.
10. To enact the social programs and spending on health, education and welfare, this can help in maintaining and augmenting both physical and intangible human capital. Finally, investment should be made in the development of infrastructure in rural areas, and in high exposure regions, priority should be given to the development of more accurate systems for early warning of extreme climatic events (e.g., drought or flood) apart from appropriate relief programs and agricultural insurance.



Table 5.1.1c Agricultural features of the district of Kosi region of Bihar

District	Food grain prodn. (tonnes)	Productivity (tonnes/ha.)	Cropping intensity (%)	Livestock pop. (no./ha of net sown area)
Supaul	133525	1.24	149.028	3.25
Saharsa	154053	1.30	144.04	2.51
Madhepura	111821	1.03	154.63	2.97
Araria	145911	1.21	142.78	3.71
Purnea	129002	1.22	136.61	3.67
Katihar	147094	1.47	145.83	3.12
Kishanganj	103656	1.09	137.49	2.09
Khagaria	102190	1.08	141.53	1.68

Source: SDDS-DES, Govt. of India, Bihar, 2011

Table 5.1.1d Occupational features of the district of Kosi region of Bihar from 1976-2015.

Distri ct	Cultivators (per hectare of net sown area)	Agril. Labourers (per hectare of net sown area)	Industrial workers (per hectare of net sown area)	Other workers (per hectare of net sown area)	Total worker (per hectare of net sown area)
Supau l	249	399	4	79	728
Sahars a	185	310	4	94	589
Madh epura	228	385	4	72	684
Araria	267	536	3	102	853
Purne a	220	608	4	133	961
Katiha r	201	240	6	150	898
Kisha nganj	110	201	6	66	417
Khaga ria	120	125	4	92	467

Source: census (Bihar),2011

5.2 Functional relationship of indicators

Sl. No.	Components	Indicators		Functional Relationship
1.	Demographic	a	Density of population (persons per sq. km)	↑
		b	Literacy rate (per cent)	↓
		c	Infant mortality rate(death/'000infants)	↑
2.	Climatic	a	Variance of annual rainfall (mm)	↑
		b	Variance of minimum temperature (° C)	↑
		c	Variance of maximum temperature (° C)	↑
		d	Variance of diurnal temperature (° C)	↑
3.	Agricultural	a	Total food grains (tonnes)	↓
		b	Productivity of major crops (tonnes/ha)	↓
		c	Cropping intensity (%)	↓
		d	Livestock population (number per hectare of gross cropped area)	↓
4.	Occupational	a	Number of cultivators (per hectare of net sown area)	↓
		b	Agricultural labourers (per hectare of net sown area)	↓
		c	Industrial workers (per hectare of net sown area)	↓
		d	total workers (per hectare of net sown area)	↓
		e	Non-workers (per hectare of net sown area)	↓

Table 5.3.1 Component wise Vulnerability index for the period 1976-2015 (Simple Average Score Method)

District	(1976-1985)		(1986-1995)		(1996-2005)		(2006-2015)		1976-2015	
	Vul. Index	Rank	Vul Index	Rank	Vul.index	Rank	Vul. Index	Rank	Vul. Index	Rank
Kishanganj	0.71	1	0.71	1	3.53	1	1.21	1	0.69	1
Khagaria	0.62	2	0.64	2	3.13	2	0.94	2	0.66	2
Supaul	0.42	7	0.45	5	2.12	5	0.37	8	0.55	3
Purnea	0.48	4	0.49	3	2.24	3	0.67	6	0.51	4
Madhepura	0.46	6	0.37	8	1.93	6	0.72	4	0.45	6
Saharsa	0.5	3	0.49	4	2.13	4	0.75	3	0.46	5
Araria	0.34	8	0.4	6	1.75	7	0.61	7	0.32	8
Katihar	0.46	5	0.37	7	1.74	8	0.71	5	0.33	7

Table 5.3.2a Component wise Vulnerability index for the period 1976-2015 (Patnaik and Narayanan Method)

District	P-I (1976-1985)		P-II (1986-1995)		P-III(1996-2005)		P-IV (2006-2015)		1976-2015	
	Vul. index	Rank	Vul. index	Rank	Vul. index	Rank	Vul. index	Rank	Vul. index	Rank
Kishanganj	0.89	1	0.89	1	0.024	1	0.59	1	0.81	1
Khagaria	0.78	2	0.8	2	0.021	3	0.51	4	0.8	2
Supaul	0.53	7	0.57	5	0.021	2	0.54	2	0.67	3
Purnea	0.6	4	0.61	3	0.019	4	0.52	3	0.57	4
Madhepura	0.58	5	0.46	8	0.012	8	0.3	8	0.56	5
Saharsa	0.63	3	0.61	4	0.014	7	0.37	6	0.56	6
Araria	0.42	8	0.5	6	0.015	6	0.36	7	0.37	7
Katihar	0.57	6	0.46	7	0.016	5	0.38	5	0.36	8

Table 5.3.2b Source wise percentage contribution of vulnerability index(P-I) 1976-1985 (Patnaik and Narayanan method)

District	Demographic	Climatic	Agril.	Occupational	Overall	Rank
Kishanganj	7.64	8.6	49.66	34.1	14.3	1
Khagaria	14.16	10.19	40.45	35.21	12.74	2
Purnea	23.92	16.39	43.8	15.89	9.75	3
Saharsa	20.47	17.59	31.33	30.61	9.7	4
Supaul	10.44	17.63	24.43	47.5	9.1	5
Araraia	16.01	29.25	41.23	13.51	8.01	6
Katihar	32.21	6.91	51.34	9.53	7.42	7
Madhepura	18.28	14.5	24.03	43.19	7.34	8
Overall	16.82	14.49	39.13	29.56	100	

Table 5.3.2c Source wise percentage contribution of vulnerability index (p-II) from 1986-1995 (Patnaik and Narayanan method)

District	Demographic	Climatic	Agril.	Occupational	Overall	Rank
Kishanganj	7.64	8.6	49.66	34.1	14.3	1
Khagaria	14.16	10.19	40.45	35.21	12.74	2
Purnea	23.92	16.39	43.8	15.89	9.75	3
Saharsa	20.47	17.59	31.33	30.61	9.7	4
Supaul	10.44	17.63	24.43	47.5	9.1	5
Araraia	16.01	29.25	41.23	13.51	8.01	6
Katihar	32.21	6.91	51.34	9.53	7.42	7
Madhepura	18.28	14.5	24.03	43.19	7.34	8
Overall	16.82	14.49	39.13	29.56	100	

Table 5.3.2d Source wise percentage contribution of vulnerability index (P-III) 1996-2005 (Patnaik and Narayanan method)

District	Demographic	Climatic	AgriL.	Occupational	Overall	Rank
Khagaria	62.76	4.32	17.87	15.06	29.78	1
Kishanganj	9.71	13.74	43.87	32.69	14.92	2
Supaul	20.18	15.77	17.04	47.01	9.19	3
Purnia	23.74	18.19	40.62	17.46	8.87	4
Araria	26.58	24.92	35.27	13.23	8.18	5
Saharsa	15.85	16.71	29.88	37.57	7.91	6
Madhepura	13.10	16.42	27.94	42.54	7.45	7
Katihar	12.15	15.18	59.86	12.81	5.52	8
Overall	31.77	12.87	30.13	25.22	100.00	

Table 5.3.2e Source wise percentage contribution of vulnerability index (P-IV) from 2006-2015 (Patnaik and Narayanan method)

District	Demographic	Climate	Agril.	Occupational	Overall	Rank
Kishanganj	4.74	14.50	46.28	34.48	14.14	1
Khagaria	11.59	9.93	42.59	35.89	12.49	2
Purnia	22.25	25.00	36.89	15.86	9.77	3
Saharsa	21.12	18.15	26.90	33.82	8.78	4
Supaul	12.95	19.43	17.99	49.63	8.71	5
Madhepura	16.27	15.53	27.04	41.17	7.70	6
Katihar	31.20	9.42	48.91	10.47	6.75	7
Araria	14.57	26.25	43.04	16.14	6.70	8
Overall	15.47	16.80	36.87	30.86	100	

Table 5.3.2f Source wise percentage contribution of vulnerability index from 1976-2015 (Patnaik and Narayanan method)

District	Demographic	Climate	Agril.	Occupational	Overall	Rank
Kishanganj	6.71	10.52	46.18	36.59	12.98	1
Khagaria	13.2	14.82	36.62	35.35	12.85	2
Supaul	11.32	20.52	25.53	42.64	10.69	3
Purnea	20.35	26.72	36.22	16.71	9.12	4
Madhepura	17.37	24.57	22.62	35.44	9	5
Saharsa	19.36	16.07	32.42	32.14	8.99	6
Araria	9.75	24.48	42.67	23.1	5.89	7
Katihar	36.13	27.92	23.43	12.53	5.83	8
Overall	15.42	19.41	33.92	31.25	100	

Table 5.3.3a Exposure data (Iyengar and Sudarsan's method)

District	Rainfall(mm)	Min. Temp. (° C)	Max. Temp. (° C)	Diurnal(° C)
Supaul	17198.49	17.46	37.11	10.90
Saharsa	14178.52	19.21	37.13	11.14
Madhepura	14689.82	17.88	36.64	11.19
Araria	21321.16	15.30	36.91	12.32
Purnia	16602.62	15.50	37.41	12.42
Katihar	16584.34	14.94	36.37	12.54
Kishanganj	28575.64	13.36	36.57	11.85
Khagaria	13642.84	19.61	36.67	11.19

Table 5.3.3b Spatial and temporal distribution of districts in relation to vulnerability (Iyengar and Sudarsan's method).

District	P-I (1976-1985)		P-II (1986-1995)		P-III (1996-2005)		P-IV (2006-2015)		1976-2015	
	Vul. Index	Rank	Vul. Index	Rank	Vul. Index	Rank	Vul. Index	Rank	Index	Rank
Kishanganj	0.63	1	0.67	1	0.71	1	0.7	1	0.6	1
Khagaria	0.64	2	0.65	2	0.65	2	0.6	2	0.6	2
Supaul	0.47	4	0.45	5	0.45	5	0.5	5	0.4	5
Purnia	0.41	6	0.48	3	0.48	3	0.5	3	0.4	4
Madhepura	0.42	5	0.44	6	0.46	4	0.5	6	0.5	3
Saharsa	0.51	3	0.47	4	0.45	6	0.5	4	0.3	6
Araria	0.31	8	0.38	7	0.35	7	0.3	7	0.3	7
Katihar	0.34	7	0.31	8	0.32	8	0.3	8	0.3	8

Table 5.3.3c Sensitivity data by Iyengar and Sudarsan's method

District	PD(persons per sq. km)	IMR(death/'000 infants)	Drought(mm)	Flood(mm)
Supaul	20.775	4.02	1	24500
Saharsa	17.364	4.47	1.2	32528
Madhepura	16.763	4.85	1.3	46221
Araria	21.896	4.71	1.5	42043
Purnea	20.882	4.21	1.7	55683
Katihar	19.238	4.37	2.1	33026
Kishanganj	21.954	4.79	1.8	44615
Khagaria	17.889	4.89	1.6	50840

Table 5.3.3d Adaptive Capacity (Iyengar and Sudarsan's method)

District	PRODN	Cropping intensity	Livestock	Cultivator	Total Worker	Agril.	Industrial worker	Other worker	LR
Supaul	85199	149	3	158	462	232	4	55	48
Saharsa	106421	144	3	246	640	329	4	93	47
Madhepura	104146	145	3	235	624	349	4	67	44
Araria	119737	143	4	260	850	518	6	112	46
Purnia	105666	137	4	218	826	650	3	138	43
Katihar	131775	146	3	206	836	530	7	152	42
Kishanganj	45170	137	2	130	419	262	4	64	45
Khagaria	80146	142	2	140	431	237	4	80	44

Table 5.3.4a Vulnerability index of Period (I) from 1976-1985 (Expert judgement method)

District	Exposure		Sensitivity		Adaptive capacity	
	Yij	Rank	Yij	Rank	Yij	Rank
Kishanganj	35.18	5	23.62	8	89.4	1
Khagaria	32.34	6	49.43	5	82.08	2
Supaul	39.77	3	53.11	4	51.22	3
Purnea	38.21	4	57.97	3	34.63	6
Madhepura	26.73	7	42.05	6	46.7	4
Saharsa	41.45	2	76.3	1	46.44	5
Araria	56.92	1	25.14	7	21.48	8
Katihar	13.82	8	65.53	2	28.5	7

Table 5.3.4b Degree of vulnerability for the period 1976-1985

Scale	level	Name of district
EXPOSURE		
≥ 47.96	Highly	Araria
23.15-47.96	Moderate	Supaul,SaharsaMadhepura,Purnea,Khagaria,Kishanganj
≤ 23.15	Least	Katihar
SENSITIVITY		
≥ 67.57	Highly	Saharsa
30.71-67.57	Moderate	Supaul,Madhepura,Araria,Purnea,Katihar,Khagaria
≤ 30.71	Least	Kishanganj
ADAPTIVE CAPACITY		
≥ 74.13	Highly	Kishanganj, Khagaria
25.40-74.13	Moderate	Supaul,Saharsa,Madhepura,Purnea,Katihar
≤ 25.40	Least	Araria

Table 5.3.4c Vulnerability index of Period (II)from 1986-1995 (Expert judgement method)

District	Exposure		Sensitivity		Adaptive capacity	
	yij	Rank	yij	Rank	yij	Rank
Kishanganj	35.88	6	53.84	4	86.35	1
Khagaria	37.72	5	63.29	3	77.61	2
Supaul	45.18	3	22.58	8	57.45	3
Purnea	43.32	4	74.55	1	39.36	6
Madhepura	30.81	7	40.33	7	50.9	4
Saharsa	48.15	2	51.12	5	47.06	5
Araria	60.28	1	45.41	6	26.58	7
Katihar	14.92	8	69.87	2	22.34	8

Table 5.3.4d Degree of vulnerability for the period 1986-1995

Scale	level	Name of district
EXPOSURE		
≥ 52.89	Highly	Araria
26.17-52.89	Moderate	Supaul, Saharsa, Madhepura, Purnea, Kishanganj, Khagaria
≤ 26.17	Least	Katihar
SENSITIVITY		
≥ 69.54	Highly	Purnea
35.71-69.54	Moderate	Saharsa, Madhepura, Araria, katihar, Khagaria
≤ 35.71	Least	Supaul
ADAPTIVE CAPACITY		
≥ 73.5	Highly	Kishanganj ,Khagaria
28.3-73.5	Moderate	Supaul, Saharsa, Madhepura, Purnea
≤ 28.3	Least	Katihar, Araria

Table 5.3.4e Vulnerability index of Period III from 1996-2005(Expert judgement method)

District	EXPOSURE		SENSITIVITY		ADAPTIVE CAPACITY	
	Yij	Rank	Yij	Rank	Yij	Rank
Kishanganj	53.33	1	48.84	5	86.39	1
Khagaria	32.15	6	60.7	3	77.67	2
Supaul	36.69	4	28.6	8	57.54	3
Purnea	39.97	3	71.53	1	39.26	6
Madhepura	29.95	7	40.94	6	50.9	4
Saharsa	35.85	5	53.89	4	47.07	5
Araria	49.48	2	40.19	7	26.5	7
Katihar	20.85	8	67.6	2	22.28	8

Table 5.3.4 f Ranking of indicators (Expert judgement method) from (1996-2005)

Scale	level	Name of district
EXPOSURE		
≥ 47.74	Highly	Kishanganj
26.82-47.74	Moderate	Supaul, Saharsa, Madhepura, Khagaria, Purnea, Araria
≤ 26.82	Least	Katihar
SENSITIVITY		
≥ 66.28	Highly	Purnea ,Katihar
36.79-66.28	Moderate	Saharsa, Madhepura, Kishanganj,khagaria,Araria
≤ 36.79	Least	Supaul
ADAPTIVE CAPACITY		
≥ 73.58	Highly	Kishanganj
28.32-73.58	Moderate	Supaul,Saharsa,Madhepura,Araria,Purnea,khagaria
≤ 28.32	Least	Katihar

Table 5.3.4 g Vulnerability index of (P- IV) from 2006-2015 (Expert judgement method)

District	Exposure		Sensitivity		Adaptive capacity	
	yij	Rank	yij	Rank	yij	Rank
Kishanganj	53.35	2	49.26	5	86.21	1
Khagaria	33.35	6	61.69	3	77.41	2
Supaul	44.26	3	26.93	8	57.11	3
Purnea	62.72	1	71	1	39.71	6
Madhepura	28.83	7	41.7	6	50.9	4
Saharsa	42.57	4	52.67	4	47.07	5
Araria	41.99	5	39.97	7	26.86	7
Katihar	15.87	8	67.17	2	22.54	8

Table 5.3.4 h Degree of vulnerability for the period 2006-2015

Scale	level	Name of district
EXPOSURE		
≥ 54.88	Highly	Purnea
25.86-54.88	Moderate	Supaul, Saharsa, Madhepura, Araria,khagaria,kishanganj
≤ 25.86	Least	Katihar
SENSITIVITY		
≥ 66.26	Highly	Purnea,
36.33-66.26	Moderate	Saharsa, Madhepura, Katihar, Khagaria, Kishanganj
≤ 36.33	Least	Supaul
ADAPTIVE CAPACITY		
≥ 73.36	Highly	Kishanganj
28.58-73.36	Moderate	Supaul, Saharsa, Madhepura, Araria, Purnea, Khagaria
≤ 28.58	Least	Katihar

Table 5.3.4 i Vulnerability index from 1976-2015 (Expert judgement method)

District	Exposure		Sensitivity		Adaptive capacity	
	Yij	Rank	Yij	Rank	Yij	Rank
Kishanganj	38.82	6	62.45	1	85.57	1
Khagaria	45.11	4	51.49	3	76.81	2
Supaul	55.62	2	17.5	8	58.57	3
Purnea	61.01	1	50.54	4	39.53	6
Madhepura	53.88	3	46.91	5	50.6	4
Saharsa	37.22	7	19.45	7	46.46	5
Araria	36.23	8	59.54	2	26.38	7
Katihar	41.83	5	35.38	6	22.3	8

Table 5.3.4 j Degree of vulnerability for the period 1976-2015

Scale	level	Name of district
EXPOSURE		
≥ 55.64	Highly	Purnea
36.79-55.64	Moderate	Supaul, Madhepura, Saharsha, Katihar, Khagaria, Kishanganj
≤ 36.79	Least	Araria
SENSITIVITY		
≥ 60.05	Highly	Kishanganj
25.76-60.05	Moderate	Purnea, Madhepura, Saharsha, Katihar, Khagaria, Araria
≤ 25.76	Least	Supaul
ADAPTIVE CAPACITY		
≥ 73.14	Highly	Kishanganj
28.42-73.14	Moderate	Supaul, Saharsa, Madhepura, Araria, Purnea, Khagaria
≤ 28.42	Least	Katihar

SUMMARY AND CONCLUSION

The present investigation entitled “**A study on vulnerability to agriculture in Kosi region of Bihar**” was carried out to identify the different climatic and socio-economic indicators of vulnerability as well also find out relationship between vulnerability and indicators in Kosi region of Bihar. The study was also planned to compare the vulnerability across the districts identified under Kosi region of Bihar. For present study eight district falling under Kosi region of Bihar were selected purposively. The present study was mainly based on collection of secondary data. The districts of the Kosi regions were considered as highly vulnerable with respect to anticipated future climate change. That’s why, vulnerability index was measure to manage the risk being forced to make choice that comprises human wellbeing overtime Vulnerability index is non-complex way of identification of district among the group which is vulnerable to climate change impact. The four major factors of vulnerability were taken into consideration to assess the vulnerability. This includes the demographic factors, climatic factors, agricultural factors and occupational factors. The major emphasis was laid on to quantify and compare the vulnerability among the districts which comes under the aforesaid region. For this purpose a composite vulnerability index was developed, emphasizing on the three major components namely, (i) Exposure (ii) Sensitivity and (iii) adaptive capacity. To derive the vulnerability index and draw meaningful inferences both the method of equal and unequal weight were employed as simple score method, and Patnaik and Narayanan method was used under equal weight and under unequal weight , expert judgement and iyengar and sudarshan’s method was used.

For assessment of vulnerability the agricultural factors followed by occupational factors was found to be most contributing factors for the entire district under study. However the district of Kishanganj was found to most sufferer district as for data pertaining to agricultural and climatic factors was concerned. It is because of the fact that unseasonal and prolonged rains cause damage to the crops whether in the field and also to the harvested produce kept at the threshing floor.

Therefore, identification of prone area on the basis of identified factors will help the Government and non-Government agencies to priorities and to direct their fund for the development of these districts. Unless these priorities regions are not focused in improving the adaptive capacity from the shock resulting from extreme events and climate variability could be devastating for the rural livelihood.

Study revealed that, the evidence on the impact of climate change on agriculture in those district of Bihar where found more prominent, where poverty and agricultural performance were closely associated. It may further reveal that, due to change in the climate agricultural yields was reducing significantly over the time indicating the increasing sensitivity towards agriculture sector. This finding poses an important question for future research, for the welfare of Bihar agriculture, how quickly will be able to adjust their farming practices to adapt to the changing climate and what policies or technologies will enable rapid adaptation to climate change.

Vulnerability differs substantially across the districts, Temporal as well as spatial vulnerability index of selected district revealed that the agricultural sector was the principal contributor to the overall vulnerability to climate change. Since the occupational indicators were the second largest contributors towards overall vulnerability, thus, to reduce the climate change impact, the policy makers must focus on generating better employment opportunities including income diversification options for the people in the regions where the incidences of out-migration are high. Adaptation to climate change can reduce many of its adverse impacts and can lead to enhanced benefits. Data pertaining to vulnerability across district indicated that Kishanganj district of Kosi region was more vulnerable due to heavy rainfall, lower literacy rate, high population density as well as lower yield due to insufficient levels of technology. Therefore enhancement of adaptive capacity is necessary for reducing vulnerability to climate changes encountered in the frequency and intensity of extreme events, like floods and droughts which have deep impact on agriculture and livelihood. The dependence on agriculture should be reduced, by encouraging other non-farm sources of income.

The results pertaining to component-wise and overall vulnerability indices as well as component-wise contributions to the overall vulnerability to climate change over the period from 1976 to 2015 was concerned. weight of each factor was estimated using multi-criteria decision-making techniques such as analytic hierarchal process and

finally, the vulnerability indices of agriculture to climate change in the districts of Kosi regions were developed. These districts have been tabulated as per the vulnerability rank based on which highly vulnerable, medium vulnerable and less vulnerable districts have been identified. It had been found that the Kishanganj district of Kosi region was most vulnerable, whereas the Katihar and Araria districts having low vulnerability due to their higher adaptive capacity to recover from the climatic stresses. Since the worst sufferers of climate change impacts are the rural communities, (who depends mainly on agriculture as their livelihoods), it is important to focus on the impacts of climate change on livelihoods, and re-establish the links among poverty, livelihood and environment.

It was noticed that agricultural and climatic vulnerability was major contributors in the overall vulnerability to climate change also. These factors had already been reflected under identification of factors ascribed for vulnerability to climate change as the socio-economic characteristics of the population living in the system. It is hypothesised to be a function of its exposure (to the external stressor causing vulnerability), sensitivity of the entity's outcome to the external stressor, and its adaptive capacity in overcoming the adverse impact of the stressor on its outcome.

Composite vulnerability indices for selected districts of Kosi region (Supaul, Saharsa, Madhepura, Araria, Purnia, Katihar Khagaria and Kishanganj) for the four different periods, viz 1976-1985, 1986-1995, 1996-2005 and 2006-2015 indicated that in the year 1976-1985 the district of Kishanganj ranked first and the district of Araria ranked last in the overall vulnerability to climate change. This implies that the district of Kishanganj was the most vulnerable and the district of Araria was the least vulnerable during that period.

As for contribution of sources was concerned, the agricultural sector played a significant role in ranking Kishanganj district at the first position by contributing to the tune (34.67) per cent to the overall vulnerability followed by occupational (28.96 per cent), climatic (22.45 per cent), and demographic factors (13.92 per cent) From the period 1976-1985, the district of Kishanganj ranked first in the overall vulnerability to climate change amongst all the selected districts of the region replacing Khagaria district to the second position, followed by Purnea district at the third.

In the year 1996-2005, Khagaria district retained its first position with demographic and agricultural indicators being major contributors towards the overall vulnerability to climate change. It was followed by Kishanganj and Supaul districts. hence, being the least vulnerable district with demographic indicators accounting for 31.77 percent, followed by agricultural (30.13 per cent), climatic (12.87) per cent) and occupational indicators (25.22 per cent).The values of vulnerability indices varied from 0.30 (Madhepura) to 0.59 (Kishanganj) in 1996-2005 indicating that there exists a wide variability in the factors influencing climate change. In the year 2006-2015, the district of Supaul replaced Kishanganj from the first position with reference to overall vulnerability to climate change.

From the analysis of the results obtained from the infrastructure, climatic, agricultural and demographic sector, frequency of extreme events and the vulnerability index we have many important interesting observations. The growth rate of population is on the higher side and growth rate of production is on the lower side. Also these districts shown a high value for the density of population. Hence any occurrence of extreme events is likely to be catastrophic in nature for the people will have an impact on the adaptation levels of the people. The adaptive capacity of socio-economic systems also contributes to the difficulty of documenting effects of regional climate changes observable effects may be adaptations to a climate change rather than direct impacts. Poor people find it difficult to cope with climate variability. They have a negative impact also on the relief and rehabilitation efforts and result in loss of assets thereby reducing the ability of the poor to cope up with the impacts of climate change. Impacts from climate change severely threaten the developmental efforts. This increases the vulnerability of the people in entire district of Bihar. People living in poverty will not be able to cope with the challenges posed by climate change. Therefore Assessing vulnerability of agriculture to climate change is the pre-requisite for developing and disseminating climate-smart technologies. Decision-makers and planners need this information to prepare strategy for addressing the adverse impacts of climate change and prioritize vulnerable districts for resources allocations.

Computation of adaptive capacity should be based on socio-economic indicators of agricultural technology, infrastructure and human development. These spatial datasets of the key indicators contributing to agricultural vulnerability have been generated for the future study in Bihar. and those districts, which are highly vulnerable, policy

makers should enact measures to support effective management of environmental resources, Adaptation policies should increase the resilience of farming and food systems to climate change impacts while maintaining or increasing food production. For example- New cropping practices, timing of planting, Better use of short-term and seasonal climate forecasting to reduce production risks. In order to enhance the resilience of the agriculture sector new strategies must be built around 'green' agricultural technologies, such as adaptive plant breeding, pest forecasting, rainwater harvesting and fertiliser micro dosing. An improvement in the agronomic practices of different crops such as revising planting dates, plant densities and crop sequences can help cope with the delayed rainy seasons, longer dry spells and earlier plant maturity. And enact social programs and spending on health, education and welfare, which can help in maintaining and augmenting both physical and intangible human capital. Finally, investment should be made in the development of infrastructure in rural areas, and in high exposure regions, priority should be given to the development of more accurate systems for early warning of extreme climatic events (e.g., drought or flood) apart from appropriate relief programs and agricultural insurance.



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APPENDIX-I

Spatial and temporal ranking of vulnerability index (Patnaik and Narayanan method)

DISTRICT	Period I (1976-1985)					Period II (1986-1995)					Period III (1996-2005)				
	Demo	Cli	Agri.	Occu	Ovral	Demo	Cli	Agri.	Occu	Ovral	Demo	Cli	Agri.	Occu	Ovral
Kishanganj	7	6	1	1	1	7	6	1	1	1	8	1	1	2	1
Khagaria	5	8	2	2	2	4	5	2	2	2	4	6	2	4	3
Supaul	6	7	8	3	7	8	3	7	3	5	6	4	8	1	2
Purnia	3	2	3	6	5	2	4	3	6	3	1	3	3	7	4
Madhepura	4	4	7	4	4	5	7	8	4	8	5	7	7	3	8
Saharsa	2	3	5	5	3	3	2	6	5	4	3	5	6	5	7
Araria	8	5	6	7	8	6	1	5	7	6	7	2	5	6	6
Katihar	1	1	4	8	6	1	8	4	8	7	2	8	4	8	5

Spatial and temporal ranking of districts as per vulnerability index (Patnaik and Narayanan method)

DISTRICT	Period IV (2006-2015)				Over All	Over all (1976-2015)				Over all
	Demo	Cli	Agri.	Occu		Demo	Cli	Agri.	Occu	
Kishanganj	8	2	1	2	1	7	2	1	1	1
Khagaria	4	6	2	4	4	4	7	2	3	2
Supaul	6	4	8	1	2	6	4	5	2	3
Purnia	1	1	3	7	3	2	1	3	6	4
Madhepura	5	7	7	3	8	5	6	7	4	5
Saharsa	3	5	6	5	6	3	5	4	5	6
Araria	7	3	5	6	7	8	3	6	7	7
Katihar	2	8	4	8	5	1	8	8	8	8

Demographic features of the districts of kosi Region of Bihar

District	Pop. Density		Literacy Rate (%)		Infant Mortality Rate	
	Male	Female	Male	Female	Male	Female
Supaul	52.05	47.89	71.65	46.63	7.7	7.9
Saharsa	52.32	47.68	65.22	42.73	7.5	8
Madhepura	52.19	47.74	63.82	42.75	6.3	7.9
Araria	52.25	47.75	64.15	45.18	7.9	7.8
Purnia	52.20	47.80	60.09	43.19	7.2	8.1
Katihar	52.11	47.89	60.99	45.37	7.8	8.2
Kishanganj	51.7	48.38	65.56	47.98	7.5	8
Khagaria	53.05	46.95	68.51	52.16	6.6	7.6

Agriculture features

District	Food grain production (tons)	Productivity (tons/ha.)	Cropping intensity(%)	Livestock population (no./ha of net sown area)
Supaul	142709	1.22	151	3.25
Saharsa	164591	1.32	185	2.5
Madhepura	119930	1.03	156	2.86
Araria	138533	1.24	158	3.71
Purnea	120735	1.18	136	3.68
Katihar	149551	1.37	144	3.09
Kishanganj	104826	1.07	142	1.95
Khagaria	103046	1.07	135	1.68

Climatic features of the Kosi region of Bihar

District	Annual Rainfall (mm)	Maximum temp.(°c)	Minimum temp. (°c)	Diurnal temp.(°c)
Supaul	1450	30.55	12.06	11.04
Saharsa	1360	27.06	15.35	11.41
Madhepura	1231	33.54	13.81	11.75
Araria	1713	32.4	16.01	13.08
Purnea	1470	30.93	13.8	12.84
Katihar	1264	37.38	16.23	12.99
Kishanganj	2175	38.21	13.7	12.36
Khagaria	1242	37.38	20.17	11.35

Occupational features

District	Cultivators	Agril labourers	Industrial workers	other workers	Total worker
Supaul	249	399	4	79	728
Saharsa	185	310	4	94	589
Madhepura	228	385	4	72	684
Araria	267	536	3	102	853
Purnea	220	608	4	133	961
Katihar	201	240	6	150	898
Kishanganj	110	201	6	66	417
Khagaria	120	125	4	92	467